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SOCIETY AND RELATED ACTIVITIES

Fall Meeting

The Fall Meeting of the AMERICAN WELDING SOCIETY held on October 2nd to 6th in Detroit in connection with the Annual Metal Congress marked a milestone of progress in the affairs of the AMERICAN WELDING SOCIETY. Twenty-eight technical papers were presented on a wide variety of subjects. There were special sessions on welding of non-ferrous metals, research papers, resistance welding and ship welding.

Two special features of the meeting were a stirring industrial drama of four acts entitled "The Prosperity Process" which was presented in cooperation with the International Acetylene Association and an inspection trip to the plants of the Kelsey Hayes Wheel Company and the Ford Motor Car Company. One of the features of the meeting was the large attendance at the technical sessions which ranged from two hundred to more than four hundred. Over sixteen hundred people attended the play.

The papers, together with the written discussion submitted, will be published in current issues of the JOURNAL as fast as the finances of the Society permit.

The Welding Exposition was well attended and accounted for nearly one-quarter of the entire space of the National Metal Exposition.

Special features of entertainment were provided for the ladies throughout the convention.

The AMERICAN WELDING SOCIETY Fall Meeting program closed with a dinner dance at the Book-Cadillac Hotel on Thursday evening.

Membership Campaign

Every member of the AMERICAN WELDING SOCIETY has received a personal letter from Mr. A. E. Gaynor, Chairman of the Membership Committee, announcing a member-for-member drive ending January 1, 1934.

The membership drive is particularly timely as welding is to play an important part in our industrial recovery and the AMERICAN WELDING SOCIETY is able and ready to give assistance in promoting the efficient application of the various welding and cutting processes.

Special attention is being given to securing new members in the shipbuilding, railroad, steel and public utility industries.

Some of the members of the Society have already responded and have sent in the names of their prospects. Literature is being sent direct from headquarters to each prospect which is followed up by personal solicitation on the part of the proposer.

As a special inducement to bring in new members the Board of Directors has made arrangements so that any member bringing in two or more new members is allowed a credit of 10% on his own dues for next year. Because of the small returns operating and student members are exempt from this privilege.

As a special inducement to the new members joining, they are given without further charge any one of the bulletins issued by the AMERICAN WELDING SOCIETY.

An attractive pamphlet outlining the purposes, activities, procedure and value of membership in the AMERICAN WELDING SOCIETY is being sent to all prospects. This pamphlet contains a simple application blank on the last page.

From time to time, it is intended to publish a record of those members who have cooperated with the Membership Committee in securing at least one new member. Members who have not already done so are urged to send in a list of their prospects in order to save the Society the expense of a follow-up letter.

Welding Shop Scene from "The Prosperity Process"—a Four-Act Industrial Drama Presented to an Audience of 1600 People by American Welding Society and International Acetylene Association during National Metal Week at Detroit

In this scene, a complete demonstration of welding, cutting and weld-testing was given right on the stage.

Chairman Structural Steel Research Committee Honored

Mr. Leon S. Moisseiff, Chairman of the Structural Steel Welding Research Committee of the American Bureau of Welding, has received the Louis Edward Levy Gold Medal awarded by the Franklin Institute of Philadelphia for his paper entitled "The Design, Materials and Erection of the Kill van Kull (Bayonne) Arch." The award was made on May 17th at the annual Medal Day exercises of the Franklin Institute.

Research Information

At the recent Fall Meeting of the AMERICAN WELDING SOCIETY which was held in Detroit, there was featured a number of research papers. At these sessions and at the conference of the professors interested in fundamental research work in welding, there was stressed the desirability of having the American Bureau of Welding act as a clearing house of information on all researches in the welding field now under way in this country and abroad.

Every member of the Society who is doing research work in this field or knows of any investigational work under way is urgently requested to report this information to Mr. W. Spraragen, Secretary of the American Bureau of Welding, 33 West 39th Street, New York, N. Y.

It is suggested that the problem under investigation, the location of the investigational work and the name of the investigators be included.

In the December 1932 issue of the JOURNAL OF THE AMERICAN WELDING SOCIETY there was published a list of fundamental research problems in welding compiled by the Fundamental Research Committee of the American Bureau of Welding. Members of the Society are also requested to study this report with the idea of suggesting additional problems needing investigational work or some which may now be omitted. It is the intention of the Fundamental Research Committee to shortly compile a new list of fundamental research problems.

New Handbook of Arc Welding

This book is published by The Lincoln Electric Company, Cleveland, Ohio.

Contains 434 pages with 500 illustrations and drawings.

Among the subjects treated in detail are: descriptions of various welding processes, definition of welding terms, classification of welds, strength of welded joints, methods of stress relieving, tabulations of speed of welding all types of joints in all positions, methods for estimating cost of weld production, structures and properties of weld metal, specifications for steels and alloys of good weldability, the welding of non-ferrous metals, comparison of limitations of rolled steel and cast iron in machine design, construction details of basic machine parts built by welding, treatise on fundamental advantages of arc welded and riveted steel structures, details of structural arc welding, welding of automotive parts, construction and repair of bridges, use of arc welding in cement plants, gas plants, machine shops, mines, refineries, pipe-lines, railroad shops, steel mills, shipyards and hundreds of other interesting subjects.

The book is bound in semi-flexible simulated leather embossed in gold. A comprehensive index has been included.

In Memoriam

At the Board of Directors Meeting of this Society held in Detroit on Monday Oct. 2, 1933, the following Resolutions were adopted:

WHEREAS, the untimely passing of James B. Green on April 24, 1933, removed from our midst a loyal and faithful member of the AMERICAN WELDING Society, an aggressive fighter in the cause of the advancement of the welding art, a man of enthusiasm and high convictions, a business associate of integrity and honor, a helpful and intelligent counsellor, a loyal friend, a man of character whose memory is revered by all who knew him; therefore, be it

RESOLVED: That the AMERICAN WELDING SOCIETY honors the memory of Mr. Green and expresses its deep sorrow for his loss by spreading this resolution upon the records of the Society and sending copies to his bereaved family and business associates as expression of its sympathy.

WHEREAS: The AMERICAN WELDING SOCIETY has learned with profound sorrow of the sudden and unexpected death on July 8th of Jesse W. Gray:

WHEREAS: In the death of Jesse W. Gray the Society has lost a sincere friend and loyal co-worker for the advancement of the welding industry: therefore be it

RESOLVED: That the AMERICAN WELDING SOCIETY hereby expresses the deep regret of its members in his death, that these resolutions be recorded in the records of the Society through publication in the Society Journal and that a copy be transmitted to his family and to the Westinghouse Electric & Manufacturing Company with which he was affiliated

SECTION ACTIVITIES

CLEVELAND

At the November 8th meeting of this Section Mr. Everett Chapman of Lukenweld, Inc., will speak on "Diesel Engines" at the Cleveland Engineering Society rooms.

The Section plans to have monthly meetings in January, February and March.

LOS ANGELES

The June meeting was held on the 15th at the Mona Lisa Cafe. Mr. R. E. Brown, Electro-Metallurgical Sales Company, presented a paper on "Practice of Welding Chromium-Nickel Steel Alloys."

The 1933–1934 season will open up with a meeting to be held on October 19th at the Cole's Cafeteria, Huntington Park. After the dinner members of the Section and guests plan a visit to the plant of the Western Pipe & Steel Company. Actual processes employed to fabricate the syphon for the Los Angeles Department of Water & Power Bouquet Canyon Job will be shown. This job involves the handling of steel plates from $\frac{3}{4}$ in. to $1\frac{1}{4}$ in. The seams range from 20 to 30 ft. in length.

NEW YORK

The first meeting of the 1933–1934 season, to be held on Wednesday evening, November 22nd, in the Engineering Societies Building, is to be devoted to a Aluminum Symposium and Exhibition—Non-technical discussion—Program will consist of the following papers: Resistance and Electric Welding of Aluminum, by D. I. Bohn, Aluminum Company of America; Gas Welding of Aluminum, by G. O. Hoglund, Aluminum Company of America; general talk on Welded Construction of Railroad Cars, Truck Body and Transportation Equipment (author to be announced later). Papers will be accompanied by lantern slides.

In addition to the papers there will be a general exhibit with particular stress on the architectural phases.

PHILADELPHIA

At the October 16th meeting Mr. Gilbert D. Fish, Consulting Engineer, spoke on "Adaptable Types of Welded Connections for Buildings." This talk was very interesting and the meeting was well attended.

At the November 20th meeting Mr. W. D. Halsey, Assistant Chief Engineer, Boiler Division, Hartford Steam Boiler Inspection and Insurance Company, will speak on "Boiler Code—Unfired Pressure Vessels."

PITTSBURGH

Mr. L. R. Gurley, Chairman of the Pittsburgh Section, has been transferred by his company to Chicago, making it necessary for him to relinquish his office as Chairman. Mr. Gurley was instrumental in extending the activities of this Section and in bringing to the meetings the very best speakers and papers possible to secure in the welding industry, all of which tended to bring out large attendances at every meeting.

Mr. F. M. Bernard, Vice-Chairman will act in Mr. Gurley's place for the remainder of his term.

The officers, members and friends of the Pittsburgh Section have been invited to the Association of Iron and Steel Electrical Engineers' Convention and Exposition to be held in the William Penn Hotel, Pittsburgh, on October 17th, 18th and 19th. The papers to be presented on October 19th will be of especial interest.

The next regular monthly meeting of this Section will be held in November.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-203. Electric arc welder and burner desires position. Seven years' experience with the J. K. Welding Company and the Electric Welding Company of America. Also salesman and demonstrator for the Quasi Arc Inc.

A-204. Engineer desires position. Twenty-five years' experience on structural steel design on all kinds of structures. Took course in structural steel welding with the General Electric Company. Licensed professional engineer and member of N. Y. State Society of Professional Engineers. Would like work on design of welded steel structures.

Electric Arc Welding under Water

By N. S. HIBSHMAN *and* C. D. JENSEN
with Metallurgical Study *by* W. E. HARVEY

✦Professor Hibshman is Assistant Professor of Electrical Engineering at Lehigh University. Professor Jensen is Assistant Professor of Civil Engineering at Lehigh University. Professor Harvey is Assistant Professor of Metallurgical Engineering at Lehigh University. Paper was presented at Fall Meeting, A. W. S., October 2nd to 6th, Detroit. Contribution to Fundamental Research Committee, A. B. W.

Electric Arc Welding under Water

ALTHOUGH it has been long known,[1] it cannot be said to be well nor widely known that the electric arc will continue to function when immersed in water; and it is a matter of very recent discovery that the arc may be so directed and manipulated as to produce welds of high quality between totally immersed pieces of metal. A carbon to metal arc combined with an oxygen stream has been used successfully for a number of years as an under-water metal cutting torch[2] in marine salvage and construction. But for the most part, the phenomenon of the under-water arc has, until recently, been a matter of interest only from the optical, calorimetric or chemical view-point.[3] In what follows, it will be shown that, should occasion arise, electric arc welds of good quality may be made under water with commercially available metallic electrodes. The technique of making such welds and their physical properties will be a part of the present discussion, while the metallurgical study of the same welds will be found in the paper by Professor W. E. Harvey.[4]

[1] Sir Humphrey Davy, *Journal Royal Institution*, **1**, 165 (1802).
[2] See Reference to L. H. Hagglund under acknowledgment at the end of the paper.

Fig. 1—Operator Making an Arc Weld in Glass Tank 12 In. below the Surface of the Water

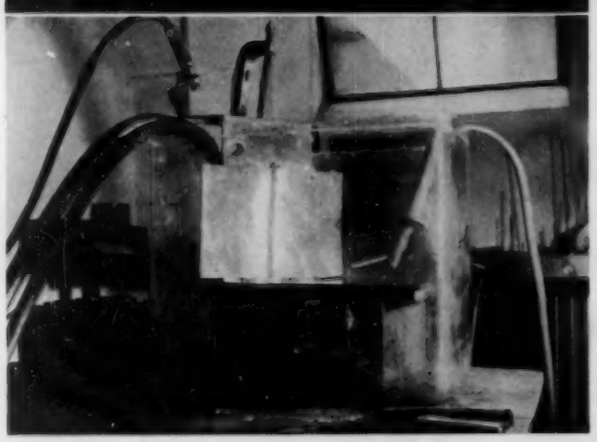


Fig. 2—View of Tank Used in Experimental Under-Water Welding. Newly Finished Vertical Weld in the Tank

When an arc is struck between metal electrodes under water it is apparent that there is immediately formed a bubble or vapor pocket at the core of which is the arc proper. Next would probably be found a mixture of incandescent gases emitted by the arc and highly superheated steam. Around these is an envelope of saturated steam in contact with the body of cool water in which the arc is immersed. The depositing of metal in any orderly fashion, essential to welding, depends upon keeping this very active bubble in a state of equilibrium. This is found to be well nigh impossible when the electrode used is a bare wire. Gas escaping from the bubble creates a disturbance in the vicinity of the arc which necessitates the most careful attention to maintain the arc at anything approaching a welding length even for a few seconds. The result of a few seconds' operation of such an arc between a bare-steel electrode and a plate is a hole in the plate of proportions, depending on the current used and the amount of travel of the electrode and a quantity of hollow metal spheres ranging from perhaps $^1/_{64}$ in. to $^3/_{16}$ in. in diameter. These quickly solidified hollow globules—mostly nearly perfect spheroids—may be of some interest as evidence pertinent to the currently discussed problem of metal transfer in the welding arc.

A few futile efforts to deposit metal with the bare-wire electrode under water quickly suggested the need for some form of shielding about the arc to control and direct its action and limit its exposure to the agitated water. The search for a practical means of enclosing the arc led to the trial of such devices as tubes and inverted funnels of various materials. These attempts were unsuccessful but served to indicate that the solution lay in the direction of shielding the arc. Bare electrodes wrapped with tape or paper or other materials proved more satisfactory, especially if the covering were applied in such a way as to induce a uniform rate of burning all the way around the tip as the electrode melted away, but following the receding tip of the wire at a distance of perhaps $^1/_8$ in. or more.

Since the advent of covered electrodes several years ago there have been found two types of commercial electrodes which rather nicely meet the requirements of under-water welding by evenly burning up at a slower rate than the metal rod, forming thereby a protecting case around the arc. It is also known that at least one other commercial type may, by the application of a thin coat of heat-resisting and water-proof enamel, be made useful for under-water welding. However, the two types now known to give good results without special treatment differ a good deal in the composition of the coating. Each has certain advantages and counter-balancing disadvantages with respect to the convenience of the operator. The first electrode, designated by the letter *F* in this paper, has a compact uniform coating with a large amount of organic material in its composition. In burning, this coating creates clouds of black smoke in the water, quickly obscuring the work from the operator unless there is a sufficient flow of fresh water to carry away

[3] See Carter and Campbell, *Transactions of the Faraday Society*, **28**, 1932, for bibliography.
[4] See article in October 1932 issue of JOURNAL OF THE AMERICAN WELDING SOCIETY.

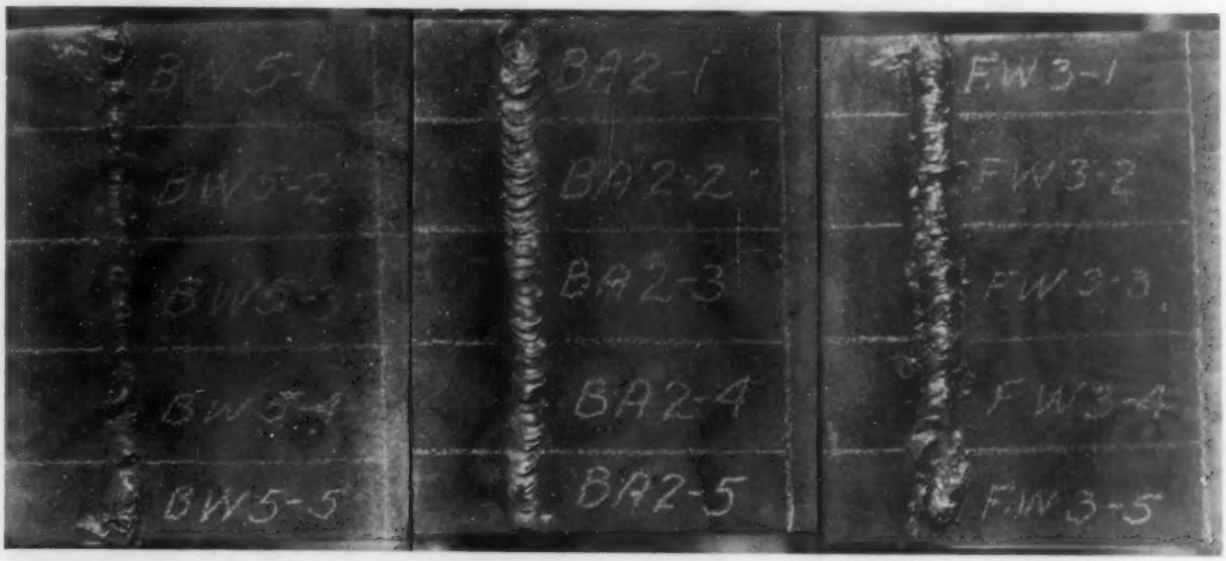


Fig. 3—Electric Arc Weld Made under Water

Fig. 4—Electric Arc Weld Made in Air, Otherwise Same Conditions as Plate in Fig. 3

Fig. 5—Another Weld Made under Water Differing from Fig. 3 in the Type of Electrode Used

the dirt. The second electrode, designated by the letter *B*, has a coating chiefly of metallic oxide which is so converted and deposited as to create little or no dirt in the water. This second type, however, leaves a heavy coating of slag on the weld which may prove inconvenient to clear away before laying a second bead. However, both types fulfill the essential requirement of maintaining a clean uniform shield of the proper depth around the arc.

Operators who have practiced welding under water describe the essential technique in terms of balancing the electrode over the arc as though it were an inflated ball to be held under the water. If it is intended only to lay a bead on a flat plate, the rim of the protecting cone or shield may be rested on the work. This, however, is seldom possible while making a weld between two plates, and considerable practice is required to control the flame even when the most suitable type of electrode is employed. "Flame control" calls for all the precautions familiar to the science of welding in air plus others peculiar to under-water work. Of course, any break or discontinuity in the covering of the electrode will permit the arc to "blow out" from under its shield. When the arc flame does escape from under the shield it may frequently be recaptured by prompt and accurate manipulation on the part of the operator. However, little sound metal is deposited when the arc is not completely under control, and patching any section of a weld is difficult, particularly if a slag-depositing type of electrode is used.

Good welding under water requires taking precautions in advance to insure as much continuous operation under good conditions as possible. The correct current must be supplied to insure proper penetration. Likewise, the arc must be steady and of the right length. Sound is the operator's best criterion of arc length. When the arc is working properly the sound is a steady, low pitched rumble but when it is too long or the flame is wild there is an irregular train of sharp explosive sounds which occasionally attain almost alarming intensity just before a two to three hundred-ampere arc is broken.

The welds described later were made in the pressed glass tank pictured in Fig. 1. The operator is shown running a bead on a horizontal plate at a depth of about 12 in. He is watching the arc through the side of the tank and through a piece of No. 4 Willson welding glass. Water is being circulated continuously so that its temperature does not rise appreciably above 25° C. Current and arc voltage were noted at each attempt to weld.

Figure 2 is a closer view of the same tank showing a completed vertical weld in place. This figure serves perhaps better than number one to show the limited space in which the work was done and to suggest the probability that at least better looking welds than those to be shown later could be made under water, if more comfortable working space were given the operator.

The source of power used in making the welds described below was a 125-volt, constant potential D.C. bus. The arc current was regulated by means of a rheostat. Several modern welding generators were, however, tried at different times and found satisfactory for the work.

Figure 3 is a general view of one side of a horizontal double-V butt weld made between two $^3/_8$-in. structural steel plates under water. The welding conditions were as follows: $^3/_{16}$-in. electrodes, 210 amperes, 25 volts (average), polarity—work positive.

Figure 4 is a similar view of a weld made by the same operator with the same type of electrode, but welding in air. The current was reduced to 165 amperes for the air weld. The letters BA2–3 and BW5–2, etc., are specimen numbers, the significance of which will be made clear in connection with Tables 1 and 2.

In comparing the welds shown in Figs. 3 and 4 it becomes apparent that, when welding under water, the deposited metal freezes very quickly showing any irregularities in the rate of travel or the behavior of the flame of the arc.

Figure 5 is a comparable view of a weld similar in all respects to that shown in Fig. 3 except that it was made with a different type of welding wire. The weld of Fig. 3 was made using the oxide-coated electrode, *B*, mentioned earlier in the discussion, while that of Fig. 5 was made with the type using the coating of organic material, *F*. No important difference has been noted in the quality of the welds made with these two types of wire. The one with the organic coating shows more tendency to cut deeply into the plate when used under water than does the oxide-coated wire.

Figure 6 shows two horizontal fillet welds between $^1/_2$-in. structural steel plates. Like the butt welds shown above, these under-water fillet welds show a rough ex-

Fig. 6—Horizontal Fillet Welds Made under Water

terior. Several cross sections cut through such welds showed excellent penetration and soundness, but considerable care was necessary to secure fusion at the roots of the welds.

Tension and free-bend tests were made of a few specimens of welds made under water and of similar welds made by the same operator in air. The results are given in Tables 1 and 2. The sketches at the top of each table describe the dimensions of the test-pieces showing also by number the location of the coupon in the test-piece. The outside coupons in each plate were set aside for metallurgical studies. In the tension tests it should be noted that the welds were single-V butt welds between $^1/_4$-in. plate with a "wash bead" on the back side. The current for the under-water welds was on the average 200 amperes. The air welds required from 150 to 170 amperes. The electrodes were $^3/_{16}$ in. in diameter. The numbering of the specimens is explained by the following examples: BW5–1 (Fig. 3) represents the fifth plate welded with the electrodes which have been designated *B* in this paper. The *W* indicates that the welding took place under water, while the "–1" determines the position of the coupon in the plate. Coupon BA2–3 (Fig. 4) was the middle coupon of the second plate welded in air with the *B* electrodes.

In connection with Table 1 it is to be noted that all of the coupons made under water broke outside of the weld (see Fig. 7). This was not the case with some of those made in air by the same operator and under comparable conditions. This is typical of the results of numerous tests, but need not be taken to prove that welds of higher tensile strength can be made in water than in air. It probably means that the operator who made the specimens had been concentrating on under-water welding for some time and had the technique for that work a little better in hand at the moment than the technique of air welding. This proved particularly true in making the specimens for the free-bend test, such poor fusion being obtained on some of the double-V specimens welded in air that it was necessary to make new specimens. The results of tests such as illustrated in Table 1 do, however, lead to the conclusion that welds made under water can be expected to have the same tensile strength as comparable welds made in air.

Table 2 gives the results of free-bend tests on typical specimens of welds made in air and under water. These tests indicate a slightly lower ductility for the under-water welds than for the welds made in air. Figure 8 is a photograph of some of the free-bend test coupons described in Table 2. These were double-V welds between $^3/_8$-in. plates. The current was about 200 amperes for the under-water welds and from 150 to 170 amperes for the similar welds made in air.

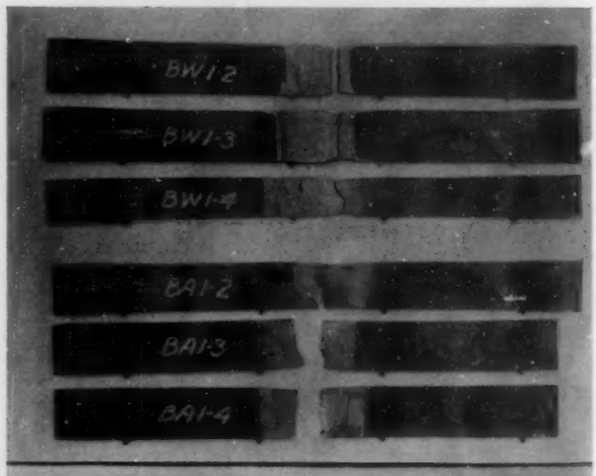
The arc voltages observed during under-water welding seem to be characteristic of the types of wire used. *B*-type of wire worked best at from 23 to 28 volts under water, while *F*-type required from 30 to 35 volts.

While acceptable vertical welds have been made under water, considerably more difficulty with flame control has been experienced in their making than has been the case with the horizontal welds described above. It is suspected that the difficulties are due to awkward manipulation and poor vision in the experimental arrangement used, rather than to any inherent difficulty embodied in making vertical welds under water.

Whereas all of the welds exhibited above were made in the glass tank pictured in Figs. 1 and 2, some welding was tried under about six feet of water with the operator working in full diving equipment. These experiments, made before the process had been perfected to its present form, indicated that with reasonably clear water and the help of modern under-water incandescent lamps of high wattage, electric arc welding could be done on a practical scale in connection with diving operations.

Other experiments established the fact that in a saturated solution of salt water welding may be carried on

Fig. 7—Broken Coupons of Welds Corresponding to Table 1



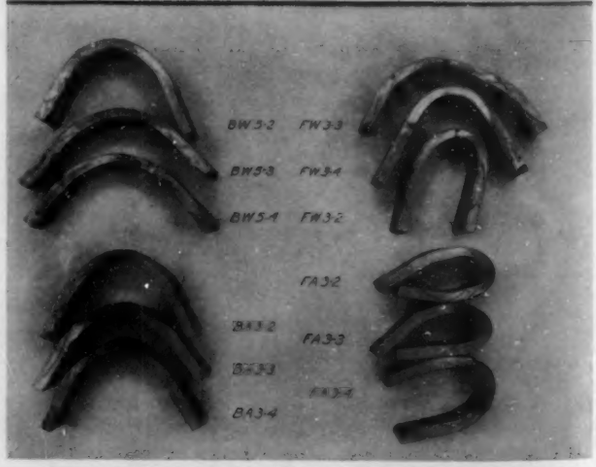
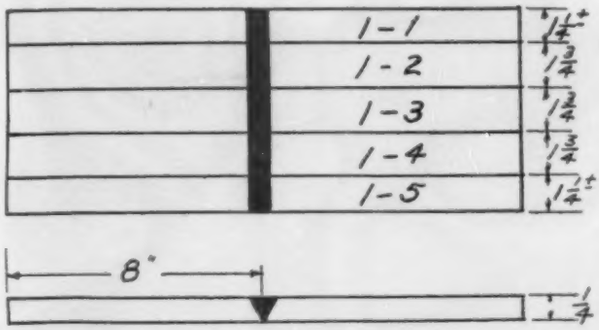
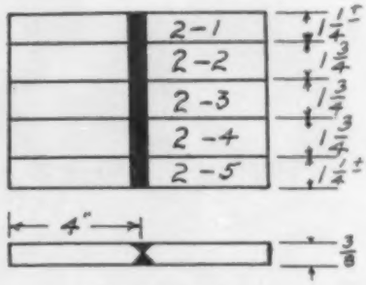


Fig. 8—Free-bend Test Coupons Corresponding to Table 2



Tension Specimens



Free-Bend Specimens

Table 1—Tension Specimens

	Specimen	Section	Area	Yield Point, Total	Yield Point, Unit	Ultimate, Total	Ultimate, Unit	Failure
In Water	BW1-2	1.80 x 0.211	0.380	15,360	40,420	21,230	55,900	Outside of weld
	BW1-3	1.83 x 0.224	0.410	15,730	38,400	22,040	53,750	Outside of weld
	BW1-4	1.38 x 0.226	0.312	11,850	38,000	16,760	53,700	Outside of weld
	FW1-2	1.65 x 0.170	0.280	13,850	49,500	15,340	54,800	Outside of weld
	FW1-3	1.65 x 0.159	0.262	....	....	14,270	54,400	Outside of weld
	FW1-4	1.63 x 0.173	0.282	13,875	49,400	16,050	56,800	Outside of weld
In Air	BA1-2	1.66 x 0.227	0.377	14,180	37,600	20,280	53,800	In weld
	BA1-3	1.67 x 0.210	0.351	14,600	41,600	17,290	49,300	Progressive from edge
	BA1-4	1.67 x 0.211	0.352	14,000	39,800	16,340	46,400	Progressive from flaw
	FA 1-2	1.67 x 0.235	0.392	14,540	37,100	21,000	53,600	Outside of weld
	FA 1-3	1.67 x 0.221	0.369	14,250	38,600	20,190	54,700	Outside of weld
	FA 1-4	1.66 x 0.241	0.400	13,900	34,700	20,670	51,700	Outside of weld

Table 2—Free-Bend Specimens

	Specimen	Section	Punch Marks, Original	Punch Marks, Final	Per Cent Elongation	Remarks
In Water	BW5-2	1.7 x 0.35	0.500	0.58	16	Began cracking at edge
	BW5-3	1.7 x 0.34	0.500	0.55	10	Began cracking at edge
	BW5-4	1.7 x 0.30	0.500	0.56	12	Cracked in middle
	FW3-2	1.7 x 0.34	0.495	0.585	18	Cracked simultaneously across section
	FW3-3	1.7 x 0.34	0.500	0.585	17	Cracked at 1/4 pt.
	FW3-4	1.7 x 0.26	0.505	0.535	7	Crack began at edge
	BA2-2	1.7 x 0.36	0.510	0.59	16	No fusion in middle third of section
	BA2-3	1.7 x 0.34	0.505	0.575	14	No fusion in middle third of section
	BA2-4	1.7 x 0.33	0.500	0.57	14	No fusion in middle third of section
	Tested March 20, 1933					
In Air	BA3-2	1.65 x 0.35	0.500	0.61	22	Fractured from edge to center
	BA3-3	1.65 x 0.33	0.500	0.58	16	Fractured across weld simultaneously
	BA3-4	1.63 x 0.33	0.500	0.58	16	Fractured from edge
	FA3-2	1.65 x 0.33	0.500	0.62	24	Fractured in weld
	FA3-3	1.63 x 0.36	0.500	0.57	14	No fracture—bent outside of weld
	FA3-4	1.65 x 0.34	0.500	0.60	20	Small fractures throughout weld surface

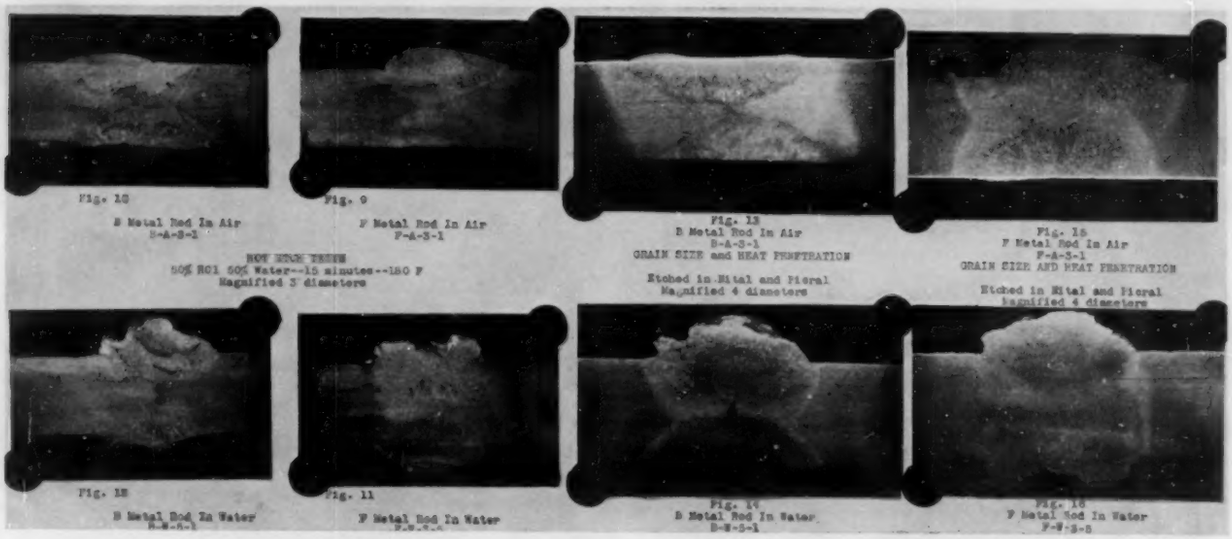
just as conveniently as in the ordinary tap water used in the work described above. Of course, when using the welding electrode in salt water, there is a considerable leakage of current before the arc is struck unless all possible area of conducting surface is insulated.

What has been said so far applies to the welding of structural steel plate under water. In the case of cast iron, some work has been done but not nearly enough to justify any statement other than that: cast iron is apparently as weldable in water as in air.

The experimental work in under-water welding outlined above leads to the conclusions that: (1) Welds of good quality may be made on low-carbon steel under water. (2) This method of welding may be found of use in experimental work where it is desired to limit the heat penetration from the weld or avoid distortion of the parent material from excessive heating or where it is desired to make a weld shielded from nitrogen and other gases present in the air.

Acknowledgment

The authors wish to take this opportunity to acknowledge the generous cooperation of Mr. L. F. Hagglund, President of the Under-Water Metal Cutting Corporation, whose use of the electric arc in cutting metal under water first suggested to them the possibilities of underwater welding. Mr. Hagglund has also lent active assistance in that part of the experimental work involving diving equipment. He is likewise authority for several statements appearing above concerning the use of the electric arc in submarine construction.



APPENDIX

Metallurgical Study of Under-Water Arc Welding

This report upon the metallurgical properties of electric arc welding under water is included as an appendix to the paper presented by Professors Hibshman and Jensen since the specimens under observation are sections of the plates welded by them for physical tests. It was considered wise to report the results of the metallurgical study as a separate section of the paper since the author is entirely interested in the microscopic studies of welds and is only slightly educated in the practice of actual welding. Thus, a decidedly unbiased opinion of the metallurgical properties of the welds should be insured.

Attention must again focus upon the facts that, while under-water welding is designed for quality welds, it may not be expected to find welds of the highest quality in the evolution of an entirely new phase of welding application; and also that the comparable air welds under study are not of the highest quality possible. It was desirable, however, to have both the water welds and air welds made by the same operator for comparative study of welding conditions under water and in the air.

The location of the specimens for metallurgical study is shown in Figs. 3 and 4. The specimens were in each case the end coupon of the welded plate and represent either the starting or finishing stages of the welding. The choice of specimens rested upon two points:

1. The center sections of the plates—probably better in quality—were available for physical testing where individual flaws in test specimens would cause acute variations in results of the tests.
2. The end sections of the plate might well be used for macrographic and micrographic study since the poorer quality sections would be under observation.

The same specimen nomenclature used by Hibshman and Jensen is used in this report in order to simplify correlation with the data in this paper. The first letter represents the type of welding rod while the second letter represents the medium in which the weld was made—either air or water.

Specimens of both water and air welds were studied. The organic compound coated rod and the oxide covered rod were examined.

Hot etch tests of the welds are shown in Figs. 9 to 12, inclusive. The hot etch test was a fifteen-minute immersion in a 50 per cent HCl : 50 per cent water solution at 180° F. The specimens were washed in hot water and dried in alcohol. Figures 9 and 11 which are the *B*-type wire welded in air and water, respectively, show two quite serious defects, namely, considerable porosity both in the weld and junction and incomplete fusion at the center of the test specimen. Figures 10 and 12 which are the *F*-type wire show some slight signs of porosity at the junction of the weld and parent metal. From the results of the hot etch tests the wires of the *F* type produced better quality welds than the *B*-type wire, both in air and water. The air results must not be considered as the best results obtainable since it has already been admitted that the under-water welder was not an experienced air welder. It might well be indicated that the specimens for metallographic study were all taken from the $^3/_8$-in. plate which had been welded for bend tests; and possibly not enough care was devoted to the fusion of the center since it plays a relatively small rôle in a bend test.

The specimens used for hot etch tests were also used for microscopic study to assure that a complete study would be made of the same section of the weld. The specimens were repolished and etched in solution first of picral and then nital for micrographic study.

The micrographic study immediately divided itself into two fields—the study of grain size and the study of the penetration distance of the welding heat into the parent metal.

Grain size of a heat treated metal is dependent upon three factors:

1. Temperature to which metal is subjected.
2. Sojourn at that temperature, i.e., if the metal is in the solid solution state.
3. Rate of cooling from that temperature.

When molten electrode metal is dropped upon two pieces of comparatively cold plate for welding, the heat transfer to the parent metal is a considerable amount since the thermal conductivity of steel is higher than that of the surrounding air; and, as a result, the parent steel absorbs a large portion of the welding heat. Thus, the parent metal adjacent to the molten weld metal is heated into the solid solution range and grain growth occurs. In the traverse of the heat from the weld metal through the parent metal the heat is dissipated and the effect of the welding heat upon the parent metal is decreased progressively with the distance from the heat source until at some particular place in the parent metal the heat effect is not sufficient to alter the grain size. Thus, in traversing from the weld metal into the parent metal, varying grain size is found—from coarse grain near the

weld metal to a very fine grain at the point where the heat is just sufficient to raise the parent metal above the solid solution temperature which is that for best grain size and then into the usually larger grain structure of the unaffected parent metal. Since strength in any one phase of a steel is dependent upon grain size it is evident why failures occur in areas adjacent to the weld.

In the under-water welding the grain size of the parent metal adjacent to the weld metal is considerably less than in air welding. The fact is due, of course, to the dissipation of a large amount of the welding heat through the water. The sojourn at elevated temperatures would be more brief and the cooling rate faster than the air welds because of the higher thermal conductivity of the water. Photomicrographs of the grain size of the weld metal and adjacent metal at any high magnification would be impossible without sectioning several micrographs. Instead the specimens were heavily overetched and micrographs of about four diameters' magnification were made and are shown in Figs. 13 to 16. The large grain areas near the weld metal can easily be seen in Figs. 13 and 15 and are hardly noticeable in the water welds as shown in Figs. 14 and 16.

The heat penetration of the various welds afforded very interesting results and the effect of the heat penetration is shown in Figs. 13–16. It was expected that in welding under water the heat penetration zone would be considerably less extended than in air welding. The results justify very markedly this prediction. It will be seen from the micrographs that the zone of heat penetration is considerably larger in the air welds than in the water welds. The heat-affected zone of the under-water welding is quite narrow and is approximately only one-fifth to one-fourth that of the penetration in the air welds. It is very interesting to note how the heat penetration zone in the water welds sharply dovetails to follow the exact lines of the weld metal. It is also very slightly noticeable in the case of the air welds.

It is interesting to note that all of the tension failures in the under-water welding physical tests are outside of the weld and are probably accounted for by the smaller grain size obtained by under-water welding. This is not true in the air welds. The water welds showed a slightly higher tensile strength which might be expected. Likewise the slightly lower ductility of figures of the water welds are justifiable from the same grain size logic.

The results of under-water welding are promising and indicate that with more experimental work and with the development of technique in water welding a new use for a tool is placed in the engineer's hands which may be of enormous value for certain applications.

Acknowledgment

The author is indebted to Mr. A. J. Ciastkewicz for his assistance in test work.

An Aircraft Manufacturer's Experience with Welding Quality Control

By P. N. JANSEN AND T. H. SPELLER

†Paper was presented at Fall Meeting, A. W. S., Detroit, October 2nd to 6th, by P. N. Jansen, Factory Manager, and T. H. Speller, Welding Engineer, Curtiss Aeroplane & Motor Co.

Introduction

AS ENGINEERS familiar with aircraft welding may too well realize, the problem of developing and operating a satisfactory quality control method for this work is made particularly difficult by the great number of joint types current in aircraft designs. Another circumstance is that the thin gages and the lack of continuity of welding on some joint types cause aircraft welding to bear little semblance to, for instance, building structure or pressure vessel welding. This makes it impossible to directly adopt anything but general principles from the very excellent codes of practice of these and other applications. Because of these greater difficulties, aircraft welding quality control has had a development out of step with the increase in demands placed upon aircraft structures. Realizing this condition, the Curtiss Aeroplane and Motor Company some time ago began the study of the problem in a more comprehensive way. The results of the study led to developing and adopting a detailed procedure control method applicable in particular to aircraft welding.

Until the new methods of control were added, locating and correcting faulty welding depended on a very rigid supervisory system of one lead man or supervisor for every ten or twelve welders and a 100% inspection of all finished welding by the regular Inspection Department. The supervisors are welders of long experience and proved skill at the trade. Their duties are to show the men under them the best method of welding new work and then to see that the work is being done as planned. The Inspection Department looks over all welding after it has been sand-blasted to find defects such as heat cracks, undercut base metal, cold laps, extremely rough or uneven fillet contours and improper fillet sizes. Work found defective is routed to a salvage room. This is a clearing house for bringing defective work from all departments, including the welding shop, to the attention of a regular committee. This committee, which is composed of a representative of both inspection and engineering, decides upon the disposition of defective parts and initiates necessary preventative measures. Army or Navy inspection is also represented when the work is connected with Government contracts.

In the study no fault could be found with the way this system was being carried out. In fact the record of failures attributable to faulty welding is remarkably low. Therefore, it was decided to make few if any alterations in existing practices. The new methods were to be in the form of agencies which would aid the welding department's judgment in planning correct welding methods for new jobs, collecting more detailed information about the ability of the individual welders, etc., and thus make welding failure still less numerous or actually non-existent. The remainder of this paper deals with the development and description of these new methods. It might be stated that only gas welding is referred to here. Also, the base metal, or material welded, is chrome molybdenum (4130) steel, exclusively.

Types of Welded Joints in Aircraft Structures

Much care was taken in classifying the various types of welding used in current aircraft designs and determining how frequently each class occurred, for one reason

Table 1

Class	Welding Time, Hrs.	Total Time, Per Cent	Average Grade Production, Per Cent	Average Grade Tests, Per Cent
Simple welds				
Fillet welds (90° to 150° included angle)				
Light (0.031–0.063)*	76.8	14.3	61.6	74.6
Medium (0.064–0.093)	67.6	12.5	68.5	
Heavy (0.094–0.250)	68.5	12.7	66.3	89.8
Lap welds				
Light (0.031–0.063)	31.6	5.9	60.6	78.2
Medium (0.064–0.093)	37.0	6.9	63.0	
Heavy (0.094–0.250)	20.4	3.8	57.2	65.3
Edge welds				
Light (0.031–0.050)	8.3	1.5	56.4	52.0
Medium (0.051–0.093)	12.4	2.3	51.0	45.6
Complex welds				
Fillet weld at an acute angle				
Light (0.031–0.063)	56.2	10.5	49.2	68.1
Heavy (0.064–0.250)	43.5	8.1	56.1	73.4
Welds with unequal heating				
Fillet welds				
Light (0.031–0.125)	2.1	0.4	54.8	
Heavy (0.126–0.250)	56.9	10.5	63.3	62.2
Lap welds				
Light (0.031–0.125)	3.1	0.6	45.4	
Heavy (0.126–0.250)	14.3	2.7	53.19	59.3
Light welds (0.031–0.063) with close edge				
Fillet	21.3	3.9	42.19	47.9
Lap	8.3	1.5	54.89	
Special complex welds				
Heavy acute angle welds with unequal heating	6.2	1.1	47.5	54.6
Light acute angle welds with unequal heating	1.0	0.2	39.4	
Light acute angle fillet weld with close edge	2.4	0.4	37.1	
Totals	537.9	100.0	54.0	64.2

* These figures refer to the base metal thickness in inches. If the two sides of the joint are of unequal thickness the figures refer to the average of the two.

because doing this indicated the problem with which we were dealing in a somewhat clearer light. This classification developed into quite a problem in itself because there apparently was no known method of doing this in existence. Consequently a means of classification had to be first worked out.

The need for a practical method of classifying became more apparent as the work of developing the method progressed. Some preliminary tests showed that one of the major causes for variation in quality was this great number of different joint types. Nine representative welders were requested to make the same type weld samples and, in order to assure their best efforts, informed of the fact that the samples would be tested. Examining and grading the welds (see Appendix A for method of grading) showed the average grade to be 56.3%. After talking over the merits or faults of each sample with the welders, a new set was welded and graded. In this case the average rate was 72.2%. The same nine men were then given a set of samples of an entirely different type, perhaps a little more difficult, but also frequently found in aircraft welding. The average grade was 51% and the retrial grade as 67.8%. This same test was repeated in a number of ways and with other groups of welders, always with the same general results. In other words, breaking the welders in on one type of weld helped very little on the second type. To be able to quickly classify new welding work and then assign it to welders of known ability in that type, therefore, became very important. Also knowledge of which weld types occur most frequently was necessary as a basis for the design of a qualification test to obtain information about the ability of new welders. A definite classifying system, together with the average grades for welds examined in each class, also is useful to the Engineering Department in the design of details more practical from a welding standpoint. It was, therefore, evident that a classifying system would be very useful.

With all these factors in mind, the classification shown in Table 1 was worked out. The basis decided upon was to divide all types of joints into a maximum of from 20 to 30 groups so that the welding technique would be similar for all the joints classified as belonging to one group. Differences in welding technique imply differences in such factors as speed of welding, size of flame, proportion of fillet, method of getting complete fusion without overheating either side of base metal, etc. To show how the welding on an airplane of more or less conventional construction would be distributed under the various classes, the welding on the Curtiss P-6E Hawk is classified in Table 1. This airplane has a welded tubular steel fuselage, welded "single strut" landing gear, wing fittings made of welded sheet steel, and various supports and brackets for controls, equipment and armament installation, also made of welded sheet and tubing. (See Fig. 1.)

Planning New Jobs

Since it was possible to bring about such marked

Fig. 1—Typical Welded Aircraft Parts

The large assembly is a "single strut" landing gear leg from the P-6E Hawk airplane. The small parts in the foreground are marked for cutting and examination.

Fig. 2—Test Sample Used to Break in Welders on Structurally Important Joints

Such samples should be arranged so that the same welding technique is used on them as is used on the actual joint. They should also be arranged for easy strength testing.

Fig. 3—Qualification Test Samples

The complete set of samples is in the foreground. Some of the complex weld samples made during a recent test are shown in the background. Sample *A*—Preliminary tests used in hiring new men. Sample *B*—Heavy fillet weld sample. Sample *C*—Light fillet weld sample. Sample *D*—Complex weld samples. Six variations. Sample *E*—Heavy lap weld sample. Sample *F*—Light lap weld sample. Sample *G*—Light edge weld sample. Sample *H*—Medium edge weld sample.

improvement by means of constructive criticisms based on the cross-sectional appearance of a similar weld, it became evident that some testing agency for aiding the leadmen in breaking in welders for new jobs could also do some very effective work by similar methods. The procedure successfully employed is for an individual familiar with both design requirements and welding problems to look over shop drawings at the time they are released for production. Certain welding jobs which appear difficult or which are particularly important structurally are picked out. The next step is to arrange that the Welding Department assign a definite crew who alone will finally weld on these jobs. Test samples are designed with the idea that they need be similar to the actual part only in the method of welding. These can be made quite inexpensively as can be seen by the sample shown in Fig. 2. The samples are welded by the picked crew and then sectioned and examined or strength tested. Strength testing is the usual thing in break-in tests because the samples, such as the one shown in Fig. 2, can be planned for easy testing. Also strength tests give a check on the factor of safety of the joint's design if it is certain that the best method of welding has been developed. Welding is not begun on the actual work until after a sufficient number of samples have been made and tested to show that an adequate welding method has been developed, and that the entire crew has mastered it. It has been found that out of a crew of, for instance, 5 men, only two may have to repeat their samples. Usually only one repetition is necessary, the welder and welding foreman having obtained enough information from the type of failure or appearance of the cross section on the first sample to correct the faults.

Value of Qualification Tests

It has also been the Company's practice for quite a few years to center responsibility in the welding foreman for hiring welders of adequate ability. The foreman gives the welder seeking employment Sample *A* in Fig. 3 to weld. The foreman bases his judgment of the man's ability to a great extent upon his performance on this sample, observing such points as the way he picks up, holds and adjusts the torch, how neat a fillet is built up, how many times he burns through the light sheet, etc. However, with this method it takes many weeks of close observation before it is possible to learn on which of the many types of work the new man is most proficient, and on which types he might need coaching. This, therefore, was another field to profitably aid the Welding Department, in this case to supply information regarding new welders' ability on the more important types of aircraft joints so that new work could be assigned to the right talent in a shorter time after employment. Because such a test involved considerable labor (about 3 hrs. for preparing samples, 5 hrs. for welding and 2 hrs. for testing), it was decided, as mentioned before, to continue basing welders' employment on the foreman's opinion as to how a man performs on the preliminary test. The new set of samples is used, therefore, for expanding and recording the information about the man of whom the foreman already has a fairly general opinion. Using the classification in Table 1, the necessary test was designed. The samples in this test are shown in Fig. 3. It can be seen that 12 classes of work are represented, all of which are found quite frequently in aircraft work. It is expected that the welder, knowing his ability is being tested, will exert his best efforts. Hence, the qualification test shows examples of his best work. Since samples of fillet welds are hard to strength test, some of the samples are sectioned and graded by examination according to the method described in Appendix A. The lap and edge weld samples, however, are arranged to be strength tested as well as etched and examined and are graded as a percentage of the unwelded sheet strength. A column in Table 1 gives the average results of tests given to 40 welders using this sample.

Since the welders given the test had been with the company for quite a while, it was interesting to compare the foreman's opinion of a welder's ability against the test record. In all but three of the 40 cases the check was quite close.

Production Welding Check

As stated above, one of the duties of the leadman, or supervisor, is to watch his men for evidences of carelessness or use of wrong technique. An effective way of aiding him along this line was found in providing a percentage check of the welder's work by destructive tests. This percentage, of course, is necessarily rather small for reasons of economy. The effect to be gained, however, is the welders' realization of the possibility of the quality of their work being checked from time to time.

Fig. 4—Storage Cabinet for Tested Welds with Card File of Welder's Records

Two record cards are kept for each welder, one for his test grades, and the other for grades from cut up production welding. The grades are collected under various type joints, so that a glance at the cards will show on which type welding the operator is proficient and thus aid in assigning new work.

The procedure set up for this phase of the work and successfully operated for quite some period is to select at random five to ten welded parts per week for every 30 welders employed. To keep the expense of this practice low, some discretion is shown so that the parts selected have not involved too much non-welding labor or that destruction of the part will not seriously affect production schedule requirements. Some effort is also made to choose work of welders whose record is erratic or incomplete. In periods of increased production it is possible to get most of the parts for test from the salvage room, since many parts find their way there because of defects such as dimensional errors or accidents in drilling holes, etc. The selection of samples is done by a non-welder such as the welding engineer or a member of the company's Inspection Department. The welding is identified through distinguishing letters which each welder stamps on the seams which he welds.

The most convincing way of making the tests would be to break up the assemblies with loads applied in a manner similar to service demands. As might be expected this would require expensive test fixtures and would be wholly impractical in most cases. Therefore, the usual method is to section the welded part at such locations as to reveal several examples of each class of welding on the part. The welds are then etched, graded according to the method of Appendix A and the grading details recorded as information regarding the welder's proficiency on that particular class of weld. The method of filing records and storing the cut-up samples is shown in Fig. 4. The results properly classified aid in assigning new work to the right welding talent. A column in Table 1 shows average grades which have been found for welds in various classes. These averages are made up from 364 weld samples in all, the most frequent occurring type, of course, having the greatest number of samples. After grading, the merits or faults of a sample are thoroughly discussed with the welder so that maximum benefit may be derived.

By examining Table 1 it can be seen that the average of test sample grades, on the whole, is 10.2% higher than the average of production welding grades. This, of course, is due to the difference of working under the pressure of knowing the piece will be tested. Certain inconsistencies are probably due to lack of sufficient samples to make up good averages.

APPENDIX A

Method of Grading by Appearance of a Cross Section

Due to the difficulty of testing complicated fittings, it was found necessary to develop a method of grading welds from the appearance of an etched cross section. The method had to be uniformly adaptable for all classes of work so that disagreements might be avoided in discussing the quality of a weld. Grading in this way has advantages and disadvantages over strength testing. The defects can be broken down into greater detail, thus giving a better clue as to how they might be avoided. However, the results of visual grading are not as convincing as are strength tests when discussing the result with individuals unfamiliar with the details of the method of grading. The method was developed keeping in mind that the grade should give an idea as to the strength of the joint. But to do this accurately was found to be very difficult and not wholly desirable because it is thought necessary to make certain deductions for such things as rough appearance, a defect having no direct relation to static strength. As it is in the case

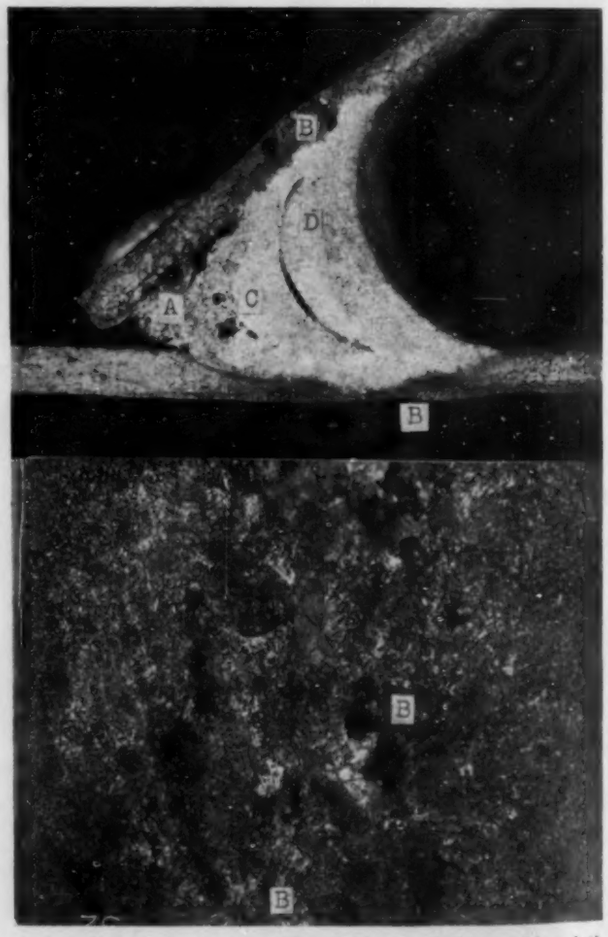


Fig. 5—Typical Defects in a Fillet Weld after Etching. (Mag. 6×)

A. Lack of fusion. *B*. Evidences of burning. *C*. Porosity. *D*. The fillet was run over a second time, the welder failing to get fusion of the additional rod with the original fillet. *E*. The fillet is too large. This caused the apparent warping of the base metal.

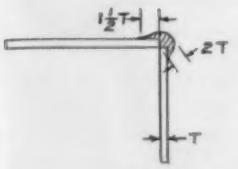


Fig. 6—Standard Proportions for Edge Welds

Table 2—Standard Fillet Proportions

	Fillet Welds			Lap Welds	
Sheet Thickness	Max. Leg	Max. Leg for Acute Angle Welds	Min. Throat	Max. Leg	Min. Fillet Thickness Measured 1.5T from Edge of Upper Sheet
0.031	0.13	0.16	0.06	0.22	0.03
0.038	0.15	0.19	0.07	0.25	0.04
0.050	0.19	0.24	0.09	0.30	0.05
0.063	0.21	0.26	0.10	0.33	0.06
0.078	0.25	0.31	0.12	0.35	0.08
0.093	0.28	0.35	0.13	0.37	0.09
0.125	0.34	0.42	0.16	0.47	0.13
0.180	0.40	0.50	0.21	0.62	0.19
0.250	0.57	0.71	0.27	0.75	0.25

of the method of classification, no claims are made that the present method of grading is completely evolved. From time to time it may become necessary to make changes in the amount of deductions made for certain defects when additional information concerning their importance becomes available.

It has been found that different individuals grading the same weld by this method will agree in most cases within 10% and usually never more than within 25%. See Fig. 5 for illustrations of some of the defects listed below.

1. Method of Grading Fillet and Lap Welds

(*a*) *Fusion.*—All joints of a similar class are first examined for adhesion of the deposited metal to the base metal. The upper part of Fig. 5 is a section of, for example, a light acute angle fillet weld of which type there may be six or eight sections cut from the weld assembly under examination. Visually estimating from the apex of the joint, the upper side has 50% fusion and the lower side 80%. Since failure would occur through the 50% of adhering metal on the upper side, that 50% is averaged into the low fusion sides of the other six or eight sections and the sounder side neglected. The resulting average would be the grade for this particular sample of light acute angle fillet weld, providing no other defects as listed below are present.

(*b*) *Appearance.*—External defects such as uneven appearance, splashed weld metal or weld metal not smoothly fused to base metal at edges, although not serious in themselves, are undesirable. Up to 10% is taken from the fusion rate, depending on how bad the defect.

(*c*) *Fillet Sizes.*—It is necessary to standardize fillet sizes between certain limits for the following reasons: Too large a fillet may be responsible for excessive sheet warpage, overheated base metal, unnecessary weight or labor expenditure and particularly interference with mating parts. Too small a fillet is rather uncommon in light and medium weight welds but obviously would result in decreased strength. Table 2 gives tentative standard fillet dimension limits.

A 5% rate deduction is made for oversize fillets, such as the one shown in Fig. 5. In cases of undersize fillets the per cent undersize is the rate deduction.

(*d*) *Porosity.*—Due to the present lack of more exact information, up to 10% is taken off for porosity or inclusions.

(*e*) *Lack of Fusion within the Fillet.*—Welders sometimes go over their work a second or third time to build up the fillet. When this is done and there is imperfect fusion between the added metal and original fillet, 10% is taken off.

(*f*) *Burning.*—Damage to the base metal due to overheating and burning is a defect equal in importance to lack of fusion when considering the over-all strength of the joint. Rightfully the joint should be considered as a chain of two links, one of which is the deposited fillet and the other the adjacent base metal. The weaker of the two should be evaluated as a strength percentage of the unwelded base metal in determining the rate for the joint. Unfortunately, up to the present, the opinion of the person examining the weld plays too great a part to base an accurate grade for the joint on the amount of burning alone. Instead the following arbitrary method of rating for this defect is resorted to. After considerable experience in examining welds, it is possible to divide the degree of damage into four or five classes, depending on how many places along a seam the sheet was burned through or the type and quantity of heat cracks. For a very slight condition 5% is deducted, for slight 10%, medium 15% and bad 20 to 30%. These percentages are taken from the fusion percentage similar to deposited metal defects. This is because the present method of evaluating burning is not definite enough to be the sole basis for condemning the quality of the joint. The likelihood of arriving at an over-all grade less than 0% is remote because excessive burning usually, but not necessarily, means a high percentage fusion. Note the evidences of burning shown in Fig. 5. The under side of the sheet (lower half of picture) shows several places where the welder burned through. Also incipient heat cracks are noticeable on both the sheet and section.

2. Method of Grading Edge Welds

In this class of weld, lack of fusion, abnormal damage to base metal, porosity or uneven appearance hardly ever occur. The main things are the location and thickness of the deposited reinforcement. The minimum proportions of the fillet are shown in Fig. 6. No maximum is set because welding conditions ordinarily limit the size. The grade for a joint is obtained by estimating the percentage that the fillet proportions differ from the standard.

Summary

The development of a method of quality control procedure for aircraft welding similar in principle to those of the pressure vessel and building structure fields, has been out of step with the increase in demands placed upon aircraft structures. One reason for this is found in the fact that the problem is particularly difficult because aircraft welders are called upon to make a very wide variety of joints all calling for a different welding technique. An attempt to remedy this inadequacy in procedure control led to the development and successful operation for a trial period of a means of aiding the Welding Department in three ways: (1) in planning the correct welding method for structurally important jobs, (2) in giving a qualification test to new welders, the results of which aid the welding foreman in assigning work to the proper welding talent. This test, incidentally, was designed after a careful survey of just what types of joints comprised the aircraft welding field and consists of several different joints which occur most frequently. The results, therefore, show on what types of aircraft joints the welder is most proficient, as well as giving his average ability. (3) Lastly, a percentage check of production welding is made by means of destructive tests of welded parts taken at random.

Small Welded Everdur Tanks

By IRA T. HOOK

†Paper was presented at Fall Meeting, A. W. S., Detroit, October 2nd to 6th, by Ira T. Hook, Research Engineer, The American Brass Co.

THERE are few conveniences about a modern home that give greater satisfaction to the entire household than an abundant supply of clean, hot water. Flash heaters are commercially obtainable and are sometimes used, but for the most part some form of hot water storage tank is required. In a former paper* methods of welding large Everdur pressure vessels were described. At this time we desire to discuss the various methods of manufacturing small copper and copper alloy tanks of sizes from 1-gal. to 300-gal. capacity.

While, as the title indicates, we are more concerned with Everdur, the manufacture and use of pure copper range boilers are discussed at some length. We must judge the corrosion resistance of the newer metal by comparison with the performance of pure copper. Accelerated corrosion tests in salt spray and various acid sprays indicate that Everdur has an equivalent or better corrosion resistance than pure copper.

Coppersmith Methods

Like the old-time blacksmith the coppersmith was a craftsman of unusual skill and artistry. Because of the nature of the copper he was not able to make pressure welds like those made by his fellow worker, the blacksmith, but he learned to do nearly as well with soft solders, silver solders, brazing alloys and rivets. Usually it was a combination of rivets and a strengthening and sealing agent. Figures 1 to 3 illustrate several methods of making seams used in the old coppersmithy.

In Fig. 1 we have a simple lapped joint with copper or brass rivets, cold headed. The sheet copper should normally be cold rolled or drawn to improve its strength to a 45,000 to 55,000 lb. per sq. in. value. If the tension in the seam is relatively high, the most common source of trouble is leaks around the rivets. The copper, being relatively thin, gradually yields in compression against the body of the rivet causing a slow leak.

* "Large Welded Everdur Pressure Vessels," JOURNAL AMERICAN WELDING SOCIETY, September 1931.

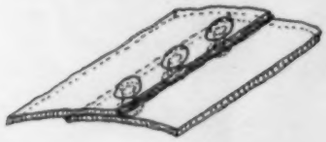


Fig. 1—Copper Sheet Riveted and Soft Soldered

Fig. 2—Scarfed Joint in Copper Sheet Silver Soldered or Brazed

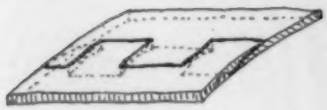


Fig. 3—Alternate Scarfs for Silver Soldering or Brazing

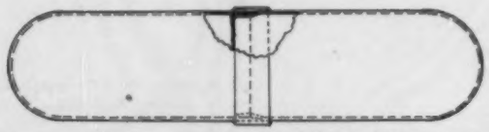


Fig. 4—Brown & Brothers Seamless, Cold Drawn Copper Range Boiler Made with Single Girth Seam

To remedy this condition such riveted seams are usually sweated with soft solder. The temperature at which this is done, 270° to 290° C. (518° to 554° F.), is still low enough to avoid seriously annealing the copper sheet, particularly if the latter is a copper carrying small amounts of certain alloying elements which have the effect of raising the annealing temperature. The soft solder performs the double function of strengthening the seam and acting as a sealing agent.

Figure 2 illustrates the simplest form of silver soldered or brazed connection. The edges are scarfed for $^1/_2$ in. to 2 in. or more, depending upon the thickness of the sheet. The edges are overlapped as shown, clamped in position and fluxed with borax or borax and boric acid, heated with some form of a blowtorch and the silver solder flowed into the joint.

The temperature at which this operation is carried out, 720° to 820° C. (1328° to 1508° F.), for silver solder, or 100° F. higher for brazing spelter, anneals the copper. This means that all of the cold work strength is dissipated and the strength is reduced to 35,000 lb. per sq. in. Hence, where the strength of the copper is of great moment, the completed seam and the copper are cold rolled.

Occasionally the scarfing is done in panels, as in Fig. 3, so that each edge alternately appears on top and bottom of the seam. This makes for symmetry but the cost is seldom justified by the slight gain in strength.

The Brazed Connection

Brazing solder could be used with either of these types of connections, or it can be applied to a square-edged butt joint or a short lapped joint. Most frequently the brazing solder or spelter solder (50% copper, 50% zinc) is used in the form of a powder or coarser granules mixed with borax. While the brazing solder may melt as low as 845° C. (1553° F.), it is usually necessary to heat the base metal well over 880° C. (1616° F.) to get a proper flow. This means, of course, dead soft copper in the seam, and within several inches thereof, and a maximum tensile strength rarely higher than 35,000 lb. per sq. in. The brazed seam does not lend itself quite as readily to cold rolling as does the silver soldered seam. The brazing spelter hardens under cold work much more rapidly than the copper or the silver solder.

Neither the silver soldering nor the brazing processes can be used as a reinforcement on account of their fluid nature when molten. Nor can they be used as a seal for a riveted connection, since the high heat necessary to place such solders will soften the rivet and cause it to lose its grip on the sheets.

Drawn Shells

As will be seen from the above, the seam was always the weakest part of a tank made up of copper or a copper alloy. The latter could be cold worked to consistently develop 55,000 lb. per sq. in. But the only type of seam in which the original cold rolled temper of the sheet metal could be retained was the riveted or riveted and soft soldered seam. This is a more or less expensive seam and is in some situations (as, for instance, exposed in a kitchen) regarded as unsightly. As was pointed out before, the silver soldering or brazing heat will

destroy the strengthening effect of cold rolling with a drop in tensile strength from 55,000 to 33,000 lb. per sq. in.

In order to eliminate as far as possible these difficulties, the Randolph, Clowes Company of Waterbury, Connecticut, in 1876 installed hydraulic equipment to draw seamless boiler shells from flat copper circles by the cupping process. Two of these seamless shells are forced together as illustrated in Fig. 4, and the overlapping rims sweated with soft solder.

This method of manufacture eliminates the severely stressed longitudinal seam and one of the girth seams. The advantage of this is readily understood when it is considered that the highly stressed longitudinal seam is entirely eliminated and only one girth seam, stressed at half the value of the longitudinal seam, retained.

The heads are integral with the body and both convex outwardly in such a shape as to suffer the least bending stress in the head or at the junction of head and body. Being cold drawn, the shell walls have a high strength of the order of 50,000 lb. per sq. in., which strength is not impaired by the method of manufacture. The seamless copper band encircling the mid-girth acts as a reinforcement, at the same time concealing the seam.

In the fifty-seven years since range boilers of this type were first manufactured, some 140,000 have been made and sold under the name of Brown & Brothers. Most of these are still in service. Figure 20 shows one after fifty-one years of service. A few of them have come back after twenty to forty-five years of service to have a leak through the solder at the soldered-in spud or the girth seam corrected.

In earlier years when the American kitchen was large, the pride of the housekeeper was the brightly polished copper range boiler which occupied a prominent place near the coal range from which it received its hot water. Under such conditions the soft soldered girth seam gave excellent service. But as the kitchen became smaller and smaller, the range boiler was relegated to the basement and the water heated with a high temperature gas burner and copper coil. Figure 5 shows such an installation. This meant periods of very hot water during which the soft solder was appreciably softened. To meet this condition the girth seam of the Brown & Brothers copper boiler is now strengthened mechanically against longitudinal pulls by bumping button-head depressions into the two half shells.

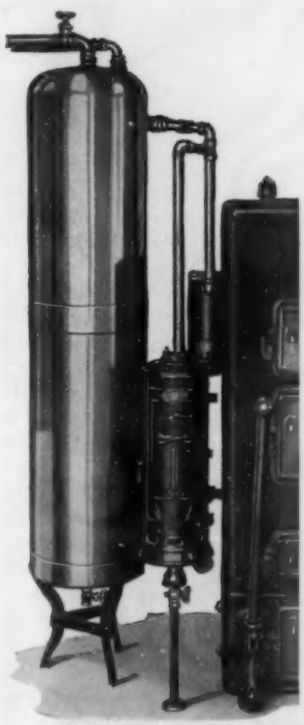


Fig. 5—Brown & Brothers Seamless Drawn Copper Range Boiler

Welded Copper Tanks

With the popularization of various welding methods many attempts were made, in fact, are still being made, to manufacture small copper tanks by welding. Two difficulties were at once apparent:

1. It was found that by no welding method thus far developed could the cold work strength of the metal be retained in the base metal adjacent to the weld. The designer, therefore, was faced with a loss in strength, measured by a drop from perhaps 50,000 lb. per sq. in. to 35,000 lb. per sq. in., and he was forced to use extra thickness throughout to compensate for the lower strength at the welded seam.

2. Worse still, the copper generally available is a very pure copper which, however, carries 0.03 to 0.07% oxygen in the form of cuprous oxide. The welding heat is prone to cause a redistribution of the cuprous oxide in a narrow zone adjacent to the weld which may further reduce the strength to only 15,000 lb. per sq. in.

A third source of difficulty for the welder, viz., high heat conductivity of copper, may be mentioned here, though in the thinner gages normally used for the 30 to 60-gal. tanks this handicap can be readily overcome by the use of sufficient heat in the welding operation.

Welding Methods on Copper

In spite of these handicaps numerous welded copper vessels have been made and put into service. Many times the important thing is to have the vessel of copper for its chemical properties, the pressures being light, or the shell supported so that soft copper would serve. When this is the case, a fusion weld in copper is readily made by the more common welding methods as the oxyacetylene torch, the carbon or the metallic arc.

In welding copper a deoxidized copper or copper alloy rod should always be used for the weld metal. This rule should be observed whether the base metal be oxygen-bearing or deoxidized copper. The more common welding rods for copper are: (1) copper deoxidized with silicon, or (2) copper deoxidized with phosphorus, (3) phosphor bronze or (4) Everdur. These rods can be used with the oxyacetylene torch or with the electric arc.

The first two, i.e., the deoxidized copper welding rods, will yield weld metal having a strength about on par with the dead soft base metal, while both the phosphor bronze (having a sufficiently high tin content, 4 to 10%) and the Everdur will yield weld metal considerably greater in strength than the soft base copper. In fact the 10% tin phosphor bronze and the Everdur weld metals will have a strength in the as-welded condition comparable to copper in the cold-rolled condition, i.e., a tensile strength of 50,000 lb. per sq. in. or better.

The principal limitations to the use of well-established welding methods to copper are found in the weakened zone of the oxygen-bearing copper and the high heat conductivity of the metal. The former can many times be overcome by hot forging the finished weld at a dull red to black heat and reheating to a bright red for recrystallizing.

The high heat conductivity limits the application of the arc, and the metallic arc in particular, to a thickness of base metal of $^3/_{16}$ in. It is difficult to raise the heat,

which in the usual welding generator means an increase in the current value, to a value high enough to heat the base metal properly without losing too much weld metal by the bad sputtering which results.

At least one electrical manufacturer has attempted to overcome this difficulty by the use of a generator having a higher working e.m.f. so that by this means a fairly steady 40-volt arc can be maintained. The higher heat energy of the long arc, with a given current value, heats the base metal to better advantage, and superheats the weld metal so that it is better able to alloy with the base metal, while the melting rate of the rod is still safely within the spattering point. Some very good welds are being made by means of the 40-volt metallic arc and a 10% tin phosphor bronze-welding rod in $^{3}/_{16}$-in. to $^{5}/_{16}$-in. thick copper.

Metal for Copper Alloy Tanks

As was pointed out by the late Mr. S. W. Miller in 1926 and by the writer in 1929, deoxidized copper sheet will weld appreciably better and with a higher strength than the more common oxygen-bearing copper. In other words, it is a comparatively simple matter to develop the strength of the dead soft deoxidized copper sheet using the oxyacetylene torch with Tobin bronze. Or a fusion weld may be made using silicon copper, phosphor bronze or Everdur welding rod. Either one of the three rods last named can be used with the metallic or carbon arc as well as the oxyacetylene torch. A yellow bronze can be applied only with the torch.

Deoxidized copper has not, however, come into general use, due in part to the rather slow progress in the welding of copper and to the relatively slight gain in welded strength, but principally to the fact that higher strength, more weldable copper alloys have become available. The most noteworthy of these high strength, weldable copper metals is the silicon-manganese copper alloy known as Everdur, patented by Mr. Charles B. Jacobs in 1925.

Properties of Everdur

Everdur "A" has many properties which fit it admirably for pressure vessels. Having 96% copper in its make-up, it has a corrosion resistance comparable to that of pure copper, while its strength, ductility (as measured by the elongation in a tensile test), weldability and general workability are decidedly superior to similar properties of pure copper.

In point of strength, for instance, some ninety-six (96) tensile tests taken at random from mill inspection records on Everdur "A" tank sheets for the month of June 1933, show the following representative values:

Property	Values of 96 Tests Maximum	Minimum	Mean
Thickness, in.	0.2584	0.0625	....
Yield point, 0.75% extension under stress, lb. per sq. in.	51,200	25,000	35,660
Tensile strength, lb. per sq. in.	75,600	58,000	66,050
Elongation in 2 in., %	78.0	54.0	64.0

Only material which shows minimum values of 55,000 lb. per sq. in. for tensile strength, 27,500 lb. per sq. in. for yield point at 0.75% extension under stress and 35% elongation in 2 in. is released for manufacture into range boilers or pressure vessels.

The Everdur "A" to which the above tabulation applies is in the annealed condition, as is indicated by the exceptionally high elongation. As such, it is readily machined, rolled into cylinders and stamped into heads or special shapes. With suitable cold rolling the strength can be raised to 100,000 lb. per sq. in. or higher with a corresponding reduction in the elongation. As will be seen, the welded tensile strength consistent with good practice should exceed 55,000 lb. per sq. in.

Everdur Welding Methods

Everdur "A" is readily welded by any of the usual methods. By one manufacturer or another, each of the four most common welding methods, viz., (1) the oxyacetylene torch, (2) the metallic arc, (3) the carbon arc and (4) the resistance seam weld, is in commercial use. In discussing these various methods we are interested principally in the ease and economy of welding as a fabricating process, and the strength, ductility and appearance of the finished weld. As for the costs, we can form only a rough estimate, since they are dependent upon such variables as production capacity and labor rates as well as the more direct welding charges such as time, heat and material costs. However, the following notes may help us to an understanding of the various elements involved in the different methods.

Oxyacetylene Welding

Everdur "A" in all thicknesses from 0.025 to $1^{1}/_{2}$ in. or more is welded by means of the oxyacetylene torch. This method works best when the material to be joined is free to come and go in the plane of the sheets. An attempt to oxyacetylene weld with the edges of the seam clamped rigidly is prone to result in hot short cracks. If the end of the seam is open $2^{1}/_{4}$ to $2^{1}/_{2}$% of the length of the seam, it will usually close properly as the seam is finished. A good deal, of course, depends upon the size and thickness of the sheet and the speed and continuity of welding.

For all sheets under discussion, i.e., up to $^{1}/_{4}$ in. in thickness, an oxyacetylene weld is invariably made in one pass. Everdur welding rod of the same composition as the base metal is used. The weld, therefore, is a true fusion weld. In fact, the one word of caution necessary to insure a strong weld is that the base metal be fused at the time the weld metal is melted into place.

Plenty of flux, in which the essential constituents are fused borax and boric acid, is required. A good commercial brazing flux will usually answer. This is one respect in which the gas welding of Everdur differs from the arc welding. The latter methods call for little or no flux.

The low heat conductivity of Everdur, approximately 8% of that of copper, as well as its moderate melting point of 1866° F. (1019° C.), enables one to complete a weld at a rapid rate and with little distortion due to spread of heat into the surrounding sheet. A slightly oxidizing flame with its greater concentration of heat (as compared to the neutral flame) is preferable. Speed in welding is desirable from the standpoint of soundness and grain size of the weld metal.

Most of the manufacturers who started welding Everdur with the oxyacetylene torch have changed to the carbon arc by reason of the greater speed, lower distortion (which means the metal can be rigidly clamped) and heat economy of the latter. The oxyacetylene torch, however, appears to find a place in welding extremely thick, $^{3}/_{4}$ in. or above, and extremely thin, 0.025 in. ± sheets.

The strength, ductility and quality of the weld made by the oxyacetylene torch are excellent. Such a weld should develop in the sheet a tensile strength of 54,000 to 58,000 lb. per sq. in. with an elongation in 2 in. of 30 to 60%. The ductility is especially noteworthy. No other method of welding Everdur produces weld

metal as ductile as this without some special treatment such as peening and annealing.

While we are concerned in this discussion more particularly with fusion welds, it may not be out of place to point out that the metal may be joined without itself being fused when the weld metal is silver solder, brazing solder or Tobin bronze. Using the latter weld metal, it is not difficult to develop the full strength of the soft Everdur sheet. The one thing of prime importance is that the seam to be welded be painted liberally with a good brazing or silver soldering flux suspended in alcohol before the heat is applied. If a film of silicon oxide is allowed to form on the base metal ahead of the brazing heat, the bronze will have only a low strength grip.

In general, the same rule applies to the soft soldering of Everdur—the surfaces to be soldered must be painted with a flux, or better still, with a flux plus finely divided solder, before the heat is applied.

Metallic Arc Welding

Everdur is readily arc welded using a metallic arc electrode wire of the same alloy as the base metal. Very high speeds are possible where an automatic welding head is available. Since the polarity is reversed, the wire melts rapidly, coming down in large drops. A long arc of 30 volts or more is commonly used with 90 to 125 amperes on a $^1/_8$-in. wire, 190 to 200 on a $^5/_{32}$-in. diameter wire and 210 to 240 on a $^3/_{16}$-in. diameter electrode.

The proper heat is important as too low a value means incomplete penetration at the bottom of the bead and entrapped gas holes at the top. Too high a heat is apt to cause hot short cracks and too great fusion of base metal. Little or no flux is used as it is not needed for the proper union of the weld metal to the base metal, and it is inclined to make the arc wild.

The quality of the weld metal deposited from the bare metallic arc electrode is not as good as that fused by the oxyacetylene torch or the carbon arc. It is usually peppered with extremely minute particles of black oxide and has a very coarse dendritic structure. For these reasons the ductility in the as-welded condition is much lower than that of metal deposited with the oxyacetylene torch, though its strength is quite high, being of the order of 52,000 lb. per sq. in., or better. As has been pointed out before, peening of the weld metal with subsequent annealing will break up the coarse dendrites into a much finer structure with marked improvement of both the ductility and strength.

Carbon Arc Welding

A number of range boiler manufacturers have found in the carbon arc a simple and economical method of welding. The edges can be clamped rigidly into position; there is very little heat to run into the sheet causing distortion and strain on the weld, the weld progresses rapidly at the rate of 12 to 30 in. per minute, and the weld metal is generally sound and reasonably ductile.

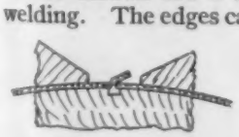


Fig. 6—Weld Made by a Carbon Arc and Upturned Edge

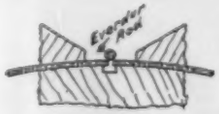


Fig. 7—Weld Metal Supplied by Round Everdur Rod Laid on Butt Joint

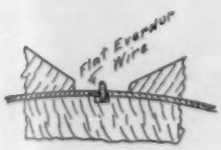


Fig. 8—Weld Made by Melting Flat Wire or Strip in Place

Moreover, uniformity may be secured by the melting of an exact quantity of metal. The weld metal is in every case identical with the base metal and may be obtained as illustrated below, Figs. 6, 7 and 8. The backer made up of copper or steel may be rounded to conform to the radius of the shell. A groove $^1/_{16}$ in. deep by approximately $^3/_{32}$ in. wide helps in aligning the edges of the sheet and allows for a narrow reinforcement on the bottom of the seam.

When the carbon arc is being used for welding in heads and spuds, a round welding rod fed into the arc as needed is the most useful. However, the edges of the shell are frequently melted down to provide weld metal for holding on the head, and the edges of the forged spud flange are sometimes melted to secure the latter.

The size of carbon will depend largely on the thickness of the sheet being welded. A carbon small enough to keep a point as it burns away is desirable. In general this means a size between $^3/_{16}$-in. and $^3/_8$-in. diameter. A high heat conductivity graphite carbon will be found economical to use in preference to a softer low-grade carbon.

A long arc is preferable to a short arc except for the difficulty of keeping it centered on the seam. A long arc will burn up the carbon to the dioxide before the carbon can reach the plate. Hence, there is less likelihood of porosity (the carbon dioxide is not as soluble in molten Everdur as carbon monoxide), and there is less trouble from carbon deposits. The magnetic pointing of the arc stream is very desirable.

The current value or arc heating capacity is best determined for a given set-up by an actual trial. It may vary from 30 amperes on very thin sheet to 250 or more amperes for the thick sheets as $^3/_{16}$ in. and thicker. The heat required depends, of course, on the speed of travel as well as the sheet thickness.

In general a low flat bead with perhaps 30 to 50% reinforcement is preferable to a thicker bead with, say, 100% reinforcement. The thinner weld will usually be found stronger and more ductile than a thicker one. This fact is mentioned because it is not generally understood. Even an experienced welder will often select a heavy bead as having greater strength than one with much less reinforcement.

Particularly is this true when spuds are being attached to a relatively thin shell or the shell is being welded to the head or bottom. In such cases it is very desirable that the under metal be not entirely fused through.

A light sprinkling of finely powdered dry flux is desirable in carbon arc welding as it helps in the flow of the metal and produces a seam having a cleaner appearance. Powdered borax glass, a good water-free brazing flux or Everdur flux (90% fused borax plus 10% sodium fluoride), may be used. Too much flux makes the carbon arc erratic.

Resistance Seam Welding

Where tanks and containers are made of very thin Everdur sheet, say, 0.010 to 0.035 in. in thickness, electric resistance spot and roller seam welding offer a very economical and attractive connection.

A popular make of kerosene stove uses an Everdur tank similar to that illustrated in Fig. 9. In manufacturing these tanks sheet metal is rolled into cylindrical form and the longitudinal seam roller seam welded.

Before inserting the heads, the point on the inner

surface tarnished by the welding heat of the longitudinal seam should be polished, as otherwise there may be a leak where it is crossed by the girth seam. The heads are now inserted and welded as illustrated in Fig. 10. At least one head must be skirted as shown in order to allow both welding rollers to contact properly with the two surfaces.

Figure 11 shows a somewhat more involved resistance seam weld. In this case two flexible Everdur diaphragms are welded simultaneously to opposite flanges of a channel-shaped Everdur ring. The job was worked out so that consistent welds are being obtained on a thyratron-controlled resistance seam welder that are strong and tight, showing no leaks when resisting 40 lb. of air pressure. Another piece of apparatus assembled by a combination of resistance spot welding and resistance seam welding is the evaporator used in small refrigerators.

The proper technique for resistance spot welding and seam welding Everdur differs materially from that used in welding steel sheets. In Everdur, as in most copper alloys, the metal must be molten to make a weld. It

Fig. 9—One-Gallon Tank Made of Thin Sheet Everdur by Resistance Seam Welding

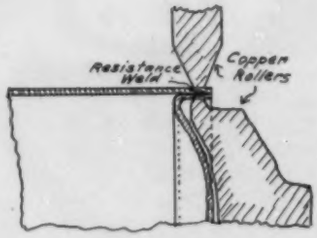


Fig. 10—Resistance Welding of Girth Seams in Making Thin-Walled Everdur Tanks

does not have a weldable, plastic range as does steel. The pressure control, therefore, must be more accurate and it is usually much lighter. The current value is, in general, slightly greater with a longer current-on period and the current density, determined by the area or width of the electrode face, is likewise important.

An extended investigation as to the resistance seam welding properties of Everdur sheet in thicknesses from 0.020 to 0.065 in. showed tensile strengths ranging from 55,250 to 61,030 lb. per sq. in. with 25 to 52% elongation in 2 in. for soft Everdur, and 62,180 to 73,500 lb. per sq. in. tensile strengths with 3 to 8% elongation in 2 in. for the cold rolled metal. The pressures on the rollers were 175 lb. for the thinner sheets and 375 lb. for the 0.065-in. thick sheets. About 70% of the capacity of a 100 kv-a. seam welder was used.

Welds Made in Commercial Practice

Welds made under laboratory supervision and welds made in commercial practice are frequently very different in point of strength and ductility. In order, therefore, to secure an accurate picture of what is being done commercially in the manufacture of Everdur tanks by welding, representative samples of commercially welded Everdur sheets were obtained from manufacturers of

Mark	Size Tested, In.	Tensile Strength, Lb. per Sq. In.	Elongation in 2 In., %	Fracture, Remarks
	Everdur Sheet before Welding			
1	0.0773 x 1.123	60,800	65.5	Silky, fine grain
1	0.0990 x 1.124	59,300	65.3	" " "
2	0.0825 x 1.500	68,700	57.0	" " "
2	0.0728 x 0.749	60,300	65.0	" " "
3	0.0747 x 1.501	60,300	73.0	" " "
3	0.1099 x 1.499	59,000	68.0	" " "
4	0.1001 x 1.497	58,700	68.5	" " "
4	0.0755 x 1.499	58,500	70.0	" " "
4	0.0453 x 0.996	58,500	65.0	" " "
	After Automatically Carbon Arc Welding (*Bead 0.145 in. thick, 0.35 in. wide*)			
1	0.0779 x 1.135	59,400	34.0	At edge of weld
1	0.0932 x 1.125	61,000	39.3	" " " "
	After Manually Carbon Arc Welding (*Beads 0.150–0.184 in. thick, 0.27–0.28 in. wide*)			
2	0.0847 x 1.113	57,930	38.2	At edge of weld
2	0.0720 x 1.172	57,000	37.0	" " " "
	(*Bead 0.155 in. thick, 0.46 in. wide*)			
3	0.0752 x 1.163	52,570	24.0	At edge of weld
3	0.1032 x 1.159	49,100	16.7	" " " "
	(*Bead 0.111 in. thick, 0.38 in. wide*)			
4	0.0443 x 1.130	55,100	37.2	At edge of weld
	Oxyacetylene Welds (*Bead 0.204 in. thick, 0.44 in. wide*)			
4	0.1064 x 1.205	58,530	42.8	At edge of weld
	(*Bead 0.158 in. thick, 0.46 in. wide*)			
4	0.0746 x 1.204	62,170	39.5	At edge of weld

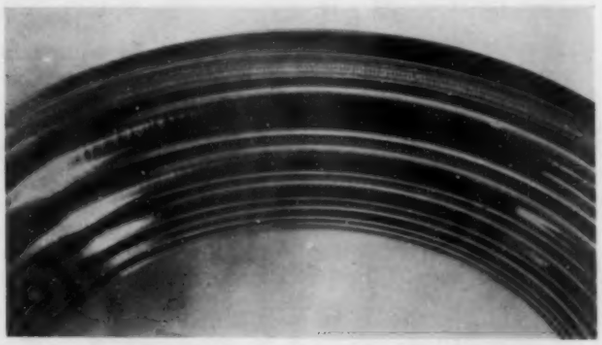


Fig. 11—Section of Oil Displacement Cell Showing Two Resistance Seam Welds,* Securing Thin Everdur Diaphragms to Everdur Ring

* Courtesy of the General Electric Company.

range boilers and tested with results as given below. Tests are given for the sheets before and after welding, the results being the averages of two or more tests in each case. In some instances the same welding shop made test welds on several thicknesses of sheets. In every case the welded samples were tested with the bead intact.

It will be noted that the results obtained with the manually operated carbon arc are slightly lower than those obtained with the automatic arc which melts an exact amount of metal per inch of seam at a definite rate.

Figure 12 is a typical section of a manual carbon arc weld. The metal is generally sound, there being comparatively few microscopically small pinholes near the top of the bead, though it is the writer's opinion that the same heat with slightly less reinforcement would have shown an increase in both soundness and strength.

Figure 13, typical of the manual carbon arc welds, explains the lower values in these welds. Clearly too much heat has been used. While the metal is sound, except for extremely minute pinholes, the abnormally large grain size indicates a low yield point and slightly low tensile strength.

Figure 14 is an excellent example of an oxyacetylene weld. The metal is perfectly sound and the weld is very narrow with ample reinforcement on top and bottom. The weld was probably made by a small, sharp (oxidizing) flame at a fast rate. The heat flow is greater into the base metal than is the case with the carbon arc, as is evidenced by the growth of the grain in the parent metal, but it is not great enough to impair the strength of the annealed metal while it does improve the ductility.

Welding Top and Bottom to the Shell

Several manufacturers of hot water heaters are using the seamless drawn shells. They at once eliminate the highly stressed longitudinal seam and one girth seam. Since the shells are cold drawn, the tensile strength of the Everdur shell wall is of the order of 80,000 to 90,000 lb. per sq. in. tensile strength with a yield point at 0.75% extension of 65,000 lb. per sq. in. or more. This means, of course, that a thinner shell can be used for a given water pressure than is the case when the minimum strength is controlled by a longitudinal weld whose strength may not exceed 55,000 lb. per sq. in.

However, even with the drawn shell, there remains considerable welding. The girth seam securing the bottom and the numerous spuds, flue and heater tubes should all be securely welded. A very simple connection, securing the Everdur bottom to the cold drawn Everdur shell, is illustrated in Fig. 15. The bottom of rather heavy gage metal is drawn with a skirt not less than $1^3/_4$ in. long having an outside diameter approximately $^1/_2$% greater than the inside diameter of the shell. The bottom is entered into the shell concave in either direction so that the edge of the shell lies hard against the skirt for at least $^3/_4$ in., leaving as much more of the skirt exposed. A carbon arc weld is run rapidly around the edge of the shell, melting it back about $^1/_{16}$ in. and covering it for another $^1/_8$ in. with weld metal. The bead will be centered just outside the edge of the shell, the bottom being sufficiently thick to take it without itself fusing all the way through.

A weld made in this manner will retain the cold work strength of the shell wall nearly to the edge of the bead. The fact that it is lying hard against the heavier bottom for at least $^1/_2$ in. beyond the weld will prevent its being overheated.

One manufacturer finishes the skirt of the bottom as the surface of a truncated cone. This makes it easy to force the shell onto the bottom and the weld is completed much as in Fig. 15. The principal objection to this method is that the shell does not fit the bottom skirt closely for more than $^1/_4$ in. and if the arc is draw out too long a hole is melted in the shell where it is not backed up by the thicker metal of the bottom. At least one other manufacturer brings the edge of the shell flush with the edge of the bottom and makes a simple edge weld with the carbon arc.

With the shells rolled up from annealed sheet of reasonably heavy gage, the heads, if placed concave outwardly, may be welded as in Fig. 15. Since the shell is, however, already in the annealed state, it is not so important to keep the heat flow into it low. More of it can be melted though the operator should be prepared to add a little reinforcement from an Everdur welding rod. Or the weld can be made by the oxyacetylene torch.

Fig. 12—Section of Manual Carbon Arc Weld in Everdur. Excessive Reinforcement, Good Strength

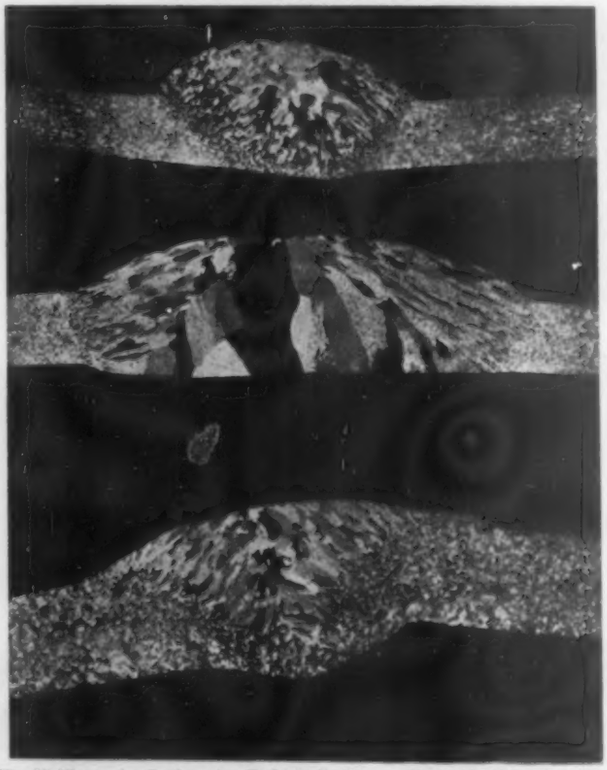


Fig. 13 (Center)—Carbon Arc Weld in Everdur. Excessive Heat, Indifferent Strength

Fig. 14 (Bottom)—Section of Oxyacetylene Weld in Everdur. Excellent Strength and Ductility

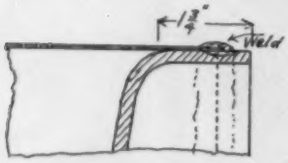


Fig. 15—Weld Connecting Relatively Heavy Bottom to the Cold Drawn Seamless Shell

Usually the top is placed convex outwardly. In this case the most convenient method of welding is illustrated in Fig. 16. In this case a skirt of approximately 1 in. will be sufficient. The shell is forced over the head until its edge stands away slightly from the head about 1/4 in. beyond the point where the knuckle radius begins. This edge is now melted down by the carbon arc as illustrated, while simultaneously the outer surface of the head is fused. The edge of the shell serves as weld metal so that little or no welding rod is needed. The strongest weld is one in which the head is not fused completely through. With metal 3/16 in. thick or thicker this is possible.

A butt weld, head to shell, can, of course, be made but this is rarely resorted to in the case of the popular-sized range boilers. Where it is employed, a 1-in. wide x 1/4-in. thick butt strap should be used on the inside of the seam as a backer and left in place.

Welding Spuds, Heater Tubes and Flues

Properly fabricated, a copper or an Everdur range boiler or heater is most certainly a quality product. A heater or tank manufacturer should, therefore, spare no pains on the smallest detail since he is to ask and receive a quality price for his product. The principal elements in good design for a spud or heater tube connection are:

1. A minimum amount of metal should be removed from the shell, since the more metal removed the higher will be the concentration of stress in the connection. In general this means the punching of a small hole in the shell and flanging the rim of the hole. If the Everdur is annealed there will be no trouble in flanging the metal cold.

2. The fitting, be it a forging, casting or drawn tube, should fit into its seat in the shell as closely as possible. Usually it should be pressed or upset into place so that the fitting and shell wall will act as a unit in resisting stress. A power press can be used to good advantage if the fittings are placed before the last head is welded in.

3. The weld should be protected from concentrated stress as much as possible and it should always be made with the thinner part overlapping the thicker part.

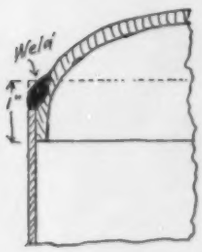


Fig. 16—Weld Connecting Annealed Everdur Shell to Everdur Head. Shell Edge Melted with Carbon Arc—Head Fused Only Partly Through

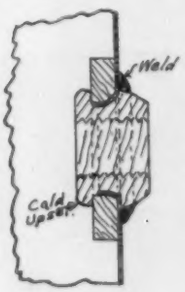


Fig. 17—Forged Everdur Spud Cold Upset into Thin-Walled Everdur Shell and Welded with Carbon Arc

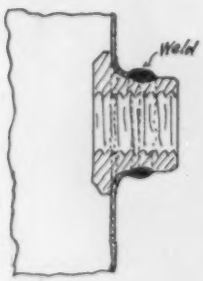


Fig. 18—Everdur Spud Welded into Everdur Shell

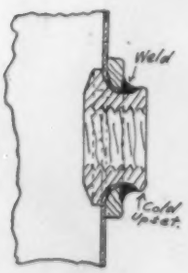


Fig. 19—Forged Everdur Spud Cold Upset and Welded to Everdur Shell and Backing Ring

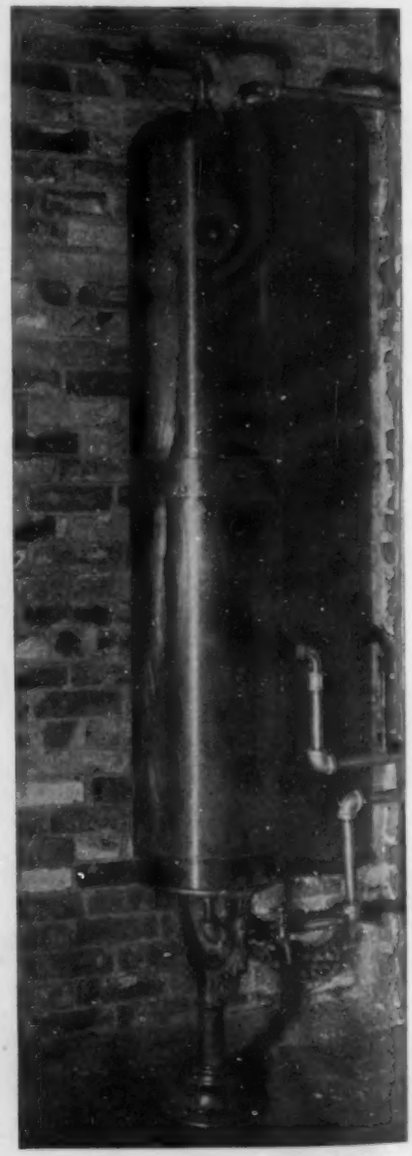


Fig. 20—Copper Range Boiler Still Good after Fifty-One Years of Service

Figures 17, 18 and 19 illustrate three spud connections which conform to these requirements. Thus, in Figs. 17 and 19, only a small hole is punched in the shell wall and the rim turned 90°. The two parts of the forged Everdur spuds are then placed and upset by means of a heavy press or hammer to pinch the shell wall and hold the assembly securely together.

In Fig. 17 the welding is actually done against the thin shell wall but the latter is closely backed up and the weld need be little more than a seal. In Figs. 18 and 19 the welding is done against the heavier wall which is desirable. In Fig. 18 no severe upsetting pressure is required but the flange at the edge of the hole should be drawn so as to hug the spud tightly. With the design of Fig. 19 the severe mechanical pinch will relieve the weld of some of the stress.

In making such welds the carbon arc with Everdur welding rod will usually be preferred, though the oxy-acetylene torch with Tobin bronze or Sil-Fos can be used.

In placing spuds in the top or bottom, owing to the thicker metal and the lower stress, it may not be necessary to take the same precautions, but a weld as in Fig. 18 or a simple edge weld between the up-turned edge of the head and the top of the spud may be used. In welding Everdur or copper flue tubes into the top or bottom of the Everdur boiler the edge weld may be used or the weld can be made against the tube.

Summary

Oftentimes in discussing the details of a project or piece of equipment we lose sight of the main objective. In order to avoid this pitfall we call attention to the "why" of the copper range boiler or heater, and similarly that of those made of Everdur. The ultimate objective of the copper water heater is economical, trouble-free, clean hot water service.

It is economical because of the high heat transfer rate of copper tubes and surfaces and the low heat radiation loss from polished copper. It is economical again because of the long life of the metal under the conditions of service. Figure 20 shows a copper boiler which gave faithful service for fifty-one years.

It is satisfactory because the common active constituents of water as oxygen, carbonic acid, sodium chloride and other mineral salts, alkalis and sulphurous acid do not appreciably attack the metal. The water is, therefore, as clean as it was before it was heated and stored in copper. The microscopically small amount of copper dissolved by the hot water is beneficial to the human system rather than otherwise. In rare cases where the active corrosive agents in the water are sufficiently strong to take up enough copper to stain a sink or bath tub where drip is permitted, a simple remedy is to tin the inside of the tank and tubes. The pure tin offers no difficulty to the soldering or welding operations and, as is well known, even acid foods like tomatoes will remain unimpaired for years in contact with tin.

Everdur "A" with its 96% of copper and its strength and ductility nearly twice that of copper, its ready fabrication by welding, its corrosion resistance equivalent to or better than that of copper becomes the last word where quality in hot water service is desired.

The Magnetic Characteristics of Deposited Metal

By WENDELL FREDERICK HESS

✦Paper was presented at Fall Meeting, A. W. S., Detroit, October 2nd to 6th, by W. F. Hess, Dept. of Engineering, Rensselaer Polytechnic Institute. Contribution to the Fundamental Research Committee, A. B. W.

THIS report covers the magnetic properties of the metal deposited by various types of commercial electrodes and also a few special alloys of iron-silicon and iron-aluminum. Both arc welding and atomic hydrogen welding were employed for the purpose of depositing the metal. The metal was tested before and after annealing to find the improvement in magnetic properties. Hydrogenization was also tried on a few typical samples. Good results were obtained with atomic hydrogen welding and also when the samples were hydrogenized.

The subject of these investigations was proposed by the Fundamental Research Committee of the AMERICAN WELDING SOCIETY in a list of subjects compiled three or four years ago. This is mentioned in appreciation of this type of committee work as a valuable service to university research workers. The welding was done by the author and most of the magnetic testing and heat treating was done under his direction by Dr. A. G. Kantayya, then a graduate student at the Rensselaer Polytechnic Institute. The interest in the subject originated with designers of electrical machinery who were contemplating the fabrication of magnetic circuits. While it is usually possible to arrange the magnetic circuit so that very little magnetic flux must pass through the welded joint, nevertheless it is of interest to know what sort of magnetic circuit the weld will make in the event that it is necessary to make use of it. Furthermore, if the weld were as good a path for magnetic flux as the parent metal, it would not be necessary to take the precautions now taken to avoid its inclusion in the magnetic circuit.

It was considered best to work with only the most representative weld metal since this would provide the data in the most suitable form for design use and for comparison of results. Many inaccuracies would be likely to occur if a welded joint were used, both because of assumptions as to dimensions of weld, and because of the inherent errors introduced by inhomogeneous specimens in the best methods of magnetic testing. The ring-ballistic method of testing was used because it is the simplest and most accurate. The samples were built up on the ends of short mild steel bars about 2 in. in diameter to a height of about 1 in. Then the bars were placed in the chuck of a lathe and the outer $^1/_4$ in. machined away. Next, the end was turned off about $^1/_4$ in., the center bored out and the ring cut off so as to have an axial width of about $^1/_2$ in. Thus, the $^1/_4$ in. nearest the bar was discarded. This insured a ring sample which included only interior weld metal.

The iron-silicon and iron-aluminum alloys were made in our own laboratory in an attempt to improve the magnetic properties. Most of the commercial electrodes were deposited by arc welding with a 300-ampere machine. A typical example of these which was low in

carbon and free from coating was tried with the atomic hydrogen equipment. The iron-silicon alloys could not be deposited by arc welding since large globules of the electrode dropped down and interfered with the arc by frequent short-circuits and interruptions. In the case of the iron-aluminum alloys it was practically impossible to deposit by the electric arc process on account of the heat liberated by the formation of aluminum oxide which kept the metal in such a fluid condition that subsequent deposition would run right off the block. However, with some difficulty a sample with 0.25% aluminum was obtained. The same trouble was experienced in depositing the metal with atomic hydrogen, but it was possible to obtain samples of 0.25 and 0.5% aluminum. Higher percentage samples containing $^3/_4$ and 1% aluminum could not be handled.

During the past summer the author made and tested some samples of the more recent types of heavily coated electrodes. One of these is intended to be used with reversed polarity and is capable of producing work of the highest quality. The scope of the work is indicated by the fact that more than twenty different samples were made and tested before and after being subjected to various heat treatments. All of the more important were made in duplicate to check results. Only a small portion of the more significant results could be included in detail by means of graphs.

Presentation and Discussion of Results

Figure 1 shows a family of magnetization and permeability curves for a typical bare low-carbon electrode deposited by arc welding. The lower permeability curve showing a maximum of about 700 is typical of bare metallic electrodes in the unannealed state. The curve next above this, showing the result of annealing at 750° C., indicates that this heat treatment produces only slight improvement in the properties. This small improvement of 100 to 150 was also characteristic. When the annealing was done at 1000° C., as is shown above, the maximum permeability was raised to about 1500. This represents a 100% improvement instead of the 20% obtained by the less thorough heat treatment. The doubling of the maximum permeability by this heat treatment was surprisingly consistent in all of the bare electrodes. The next curve, showing the result of hydrogenizing this same material, indicates a truly remarkable improvement, over 700% in this case, over the material in the deposited condition.

Fig. 1—Magnetization and Permeability Curves for Typical Bare Low-Carbon Electrode—Arc Welding

Fig. 2—Hysteresis Loops for Typical Bare Low-Carbon Electrode—Arc Welding

Fig. 3—Magnetization and Permeability Curves for Typical Bare Low-Carbon Electrode—Atomic Hydrogen

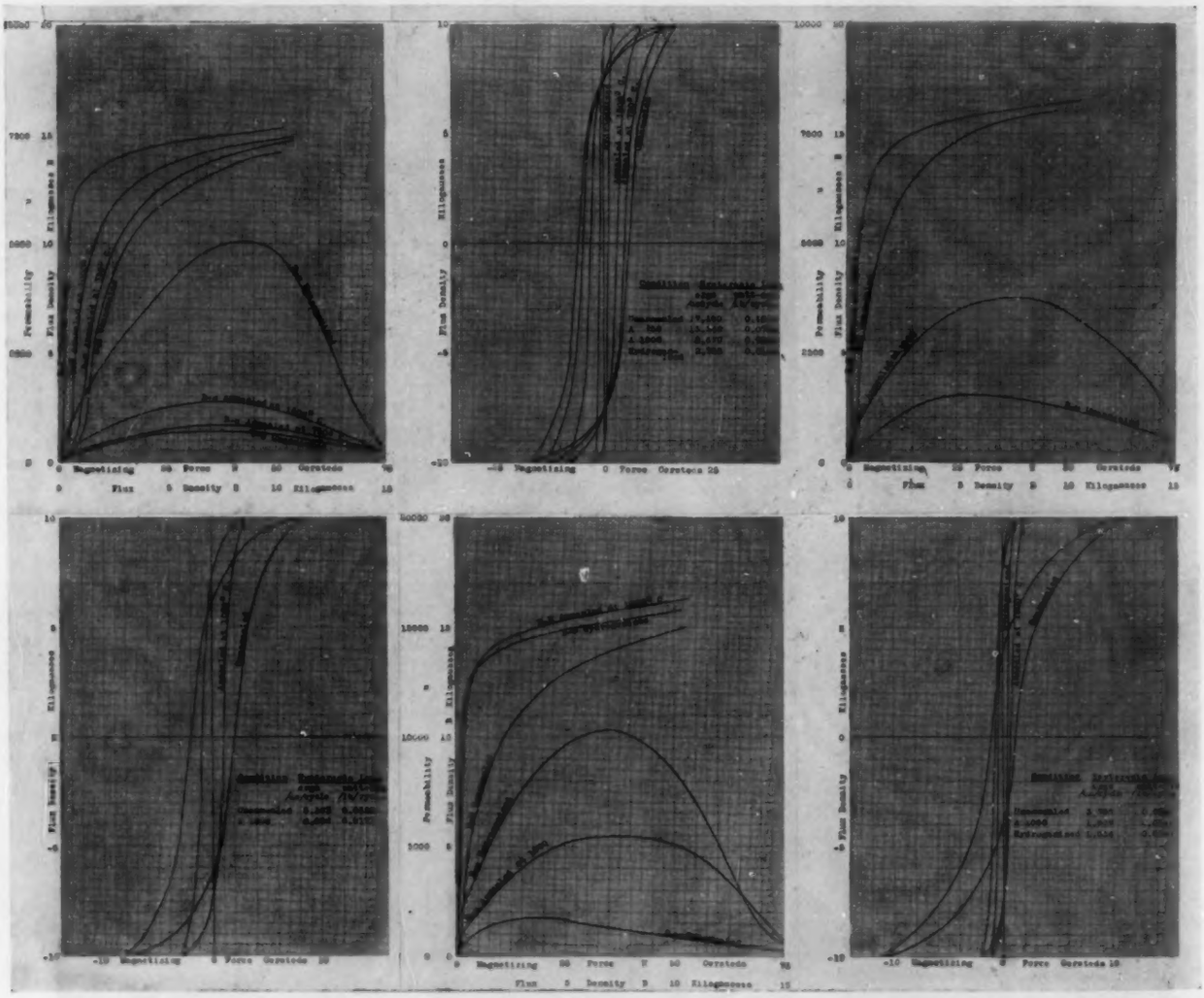


Fig. 4—Hysteresis Loops for Typical Bare Low-Carbon Electrode—Atomic Hydrogen

Fig. 5—Magnetization and Permeability Curves for Iron-Silicon Alloy (4.0% Si)—Atomic Hydrogen

Fig. 6—Hysteresis Loops for Iron-Silicon Alloy (4.0% Si)—Atomic Hydrogen

Fig. 7—Hysteresis Loops for High-Carbon Electrode—Arc Welding

Fig. 8—Hysteresis Loops for Medium Carbon Electrode—Arc Welding

Fig. 9—Hysteresis Loops for Low-Carbon Electrode—Arc Welding

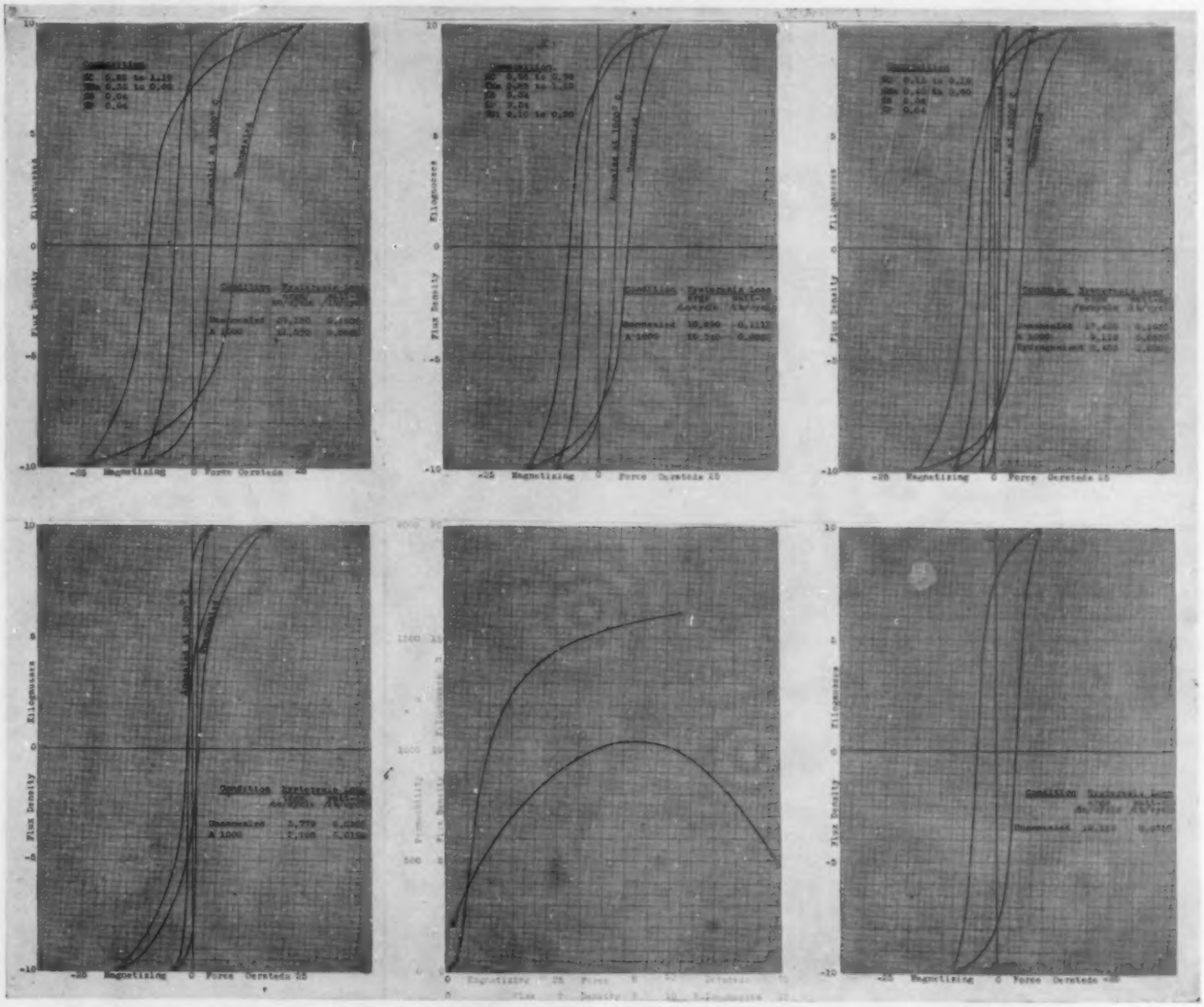


Fig. 10—Hysteresis Loops for Iron-Silicon Alloy (2.0% Si)—Atomic Hydrogen

Fig. 11—Magnetization and Permeability Curves for Reverse Polarity Downward Deposition Heavily Coated Electrode—Arc Welding

Fig. 12—Hysteresis Loop for Heavily Coated Reverse Polarity—Arc Welding

Hydrogenizing is a process of heat treatment to improve magnetic properties, discovered by Mr. Cioffi of the Bell Telephone Laboratories. As practiced in the present investigation, it consisted of keeping the samples at a temperature of 1100° C. for a period of twenty hours while moist hydrogen (hydrogen bubbled through water) was passed over them. The samples were then allowed to cool in the furnace. The temperature used in this case was less than that used by Mr. Cioffi.

The curves in Fig. 2 show the hysteresis curves for the same conditions as Fig. 1. The reduction of losses corresponds with the improvement in permeability previously noted. For example, the loss after annealing at 1000° C. is about half its value before heat treatment, and after hydrogenizing it is about one-sixth of the value in the deposited condition.

Figure 3 shows the effect of depositing the same electrode by means of the atomic hydrogen torch. This method shows a great improvement over deposition by arc welding. For example, the maximum permeability in the unannealed state is a little over 1500 or a little better than the arc-welded sample after it had been annealed at 1000° C. After annealing at 1000° C. the maximum permeability rose to 3800 or more than double its previous value.

In Fig. 4 are shown the hysteresis curves corresponding to the conditions in Fig. 3. It should be noted that these curves are plotted to a scale two and one-half times that of the curves in Fig. 2. Actually the hysteresis loss in the unannealed atomic hydrogen sample is about one-third that of the unannealed arc-welded sample, and it is even 40% less than the arc-welded sample after anneal at 1000° C. After annealing the atomic hydrogen sample at 1000° C. its hysteresis loss was less than 5% greater than the arc-welded sample after it had been hydrogenized.

Taken together Figs. 1 through 4 indicate the advantages of thorough annealing, of hydrogenizing and of deposition by means of atomic hydrogen welding.

After testing a large number of the commercial electrodes, some bare and some coated, with varying percentages of carbon, manganese and silicon, it was decided to try to get better properties by the use of special alloys. Knowing that the purest iron gives the best magnetic properties and that silicon and aluminum improve the magnetic properties of iron, alloys of these

metals with Armco iron were made up. The aluminum alloys were made by carefully adding 1/4, 1/2, 3/4 and 1% of aluminum to the molten iron immediately before casting. The iron-silicon alloys were made by adding 2, 3, 4 and 5% by weight of silicon. Table 1 gives the chemical analyses of the resulting electrode material and deposited metal for the various special iron-silicon alloys.

Table 1—Special Alloys of Iron-Silicon Type

Added by Weight	Per Cent Silicon Content Electrode Material	Deposited Metal
2.00	1.84	1.62
3.00	2.61	2.47
4.00	3.49	3.47
5.00	4.24	3.96

As previously mentioned, it was necessary to use the atomic hydrogen equipment for the deposition of the iron-silicon alloys. Since the alloys were easier to handle and gave better results than the iron-aluminum alloys, only the curves for some of the former are included in this paper. The superiority of the iron-silicon alloys was especially marked after annealing and in the matter of hysteresis losses. The loss before annealing was about two-thirds and that after annealing was about half that of the iron-aluminum alloys. The varying percentages of silicon did not produce markedly different results as regards losses. However, the lower percentages seemed to produce slightly better results. This was particularly noticed in the duplicate samples where an additional partial heat treatment was given. Here the maximum permeabilities were higher in the lower percentage samples.

Figure 5 shows a typical group of curves for the 4% iron-silicon alloy. In the unannealed condition a maximum permeability of 1360 is shown. This is no better than for bare commercial electrode deposited by atomic hydrogen. But in the matter of losses and in the effect of subsequent heat treatment the iron-silicon alloy is much better. This is to be expected from the general proposition that, other things being equal, the larger the grain size the better the magnetic properties and the fact that silicon aids greatly in the growth of grain size. After annealing at 1000° C. the alloy shows a maximum permeability of 5200. Hydrogenizing gave a maximum permeability of 10,300, the highest value reached by any of the samples. Figure 6 shows hysteresis loops for this alloy. In the unannealed condition the hysteresis loss is about one-fifth that of bare electrode deposited by arc welding. Annealed, the loss is one-half the unannealed. Hydrogenized, the loss is slightly more than one-quarter that of the unannealed.

Figures 7, 8, 9 and 10 are included to illustrate the effect of wide variations in electrode composition on the resulting hysteresis losses. Figure 7 is for a bare electrode which is of the high-carbon type. This gives very high losses. A sample weighing 1 lb. and unannealed if carried through 60 cycles per second would entail a power loss of ten watts. Figure 8 shows a medium carbon electrode which gives a loss only slightly greater than the type shown in Fig. 9 which is a low-carbon electrode. This is probably due to the fact that the medium carbon type contains a small percentage of silicon. The silicon evidently throws the carbon out of solution as neutral graphite and aids in grain growth. Figure 10 for the 2% iron-silicon alloy is plotted to the same scale as the other curves to show the remarkable reduction of losses which may be obtained by its use.

Recent improvements in the development of heavily coated electrodes made it desirable to determine the magnetic properties of these. One factor which looked promising was that the method of depositing in thin layers was known to leave the metal in an annealed condition. The high quality of these welds as shown by X-ray and other tests also pointed to the desirability of investigating them. Two samples of each of these were made up and tested this summer by the author. In order to prevent the fluid metal from running off the block, a very short section of pipe was first welded to the top of the block, forming a cup, around the edges of which the metal could be deposited. Unfortunately these samples could not be tested in the heat-treated condition because insufficient hydrogen caused by a leak in the annealing furnace caused them to be heavily oxidized. However, the thing we were most interested in was the effect produced in these electrodes by the annealing effect during deposition. The direct polarity general purpose type showed so slight an improvement over the bare electrode that the results for it are not included. The reverse polarity downward deposition type did show the expected improvement to a considerable extent. The curves for it are shown in Figs. 11 and 12. The maximum permeability of 1040 and the hysteresis loss are such as would be obtained with a bare electrode of similar composition if it had been annealed at a temperature somewhere between 750° and 1000° C.

Conclusions

It might be well to sum up the several factors which make for good magnetic properties in metal deposited by welding. If no further heat treatment is possible and arc welding must be used, the best results will be obtained by the use of an electrode of the heavily coated type designed to meet A. S. M. E. Class I requirements. Caution must be used in this connection, however, because many of the heavily coated electrodes give only a slight improvement in properties. This may be due either to the electrode-containing materials which adversely affect magnetic properties, or to impurities introduced by the coating. Electrodes high in manganese are very poor magnetically.

If atomic hydrogen welding equipment is available, its use will produce marked improvement in magnetic properties even with bare electrodes of good quality and low-carbon content. The hysteresis losses may be reduced 35% by use of a special alloy containing about 2% of silicon. Such an electrode is not now to the author's knowledge available on the market. It might even be desirable to make such an electrode in the heavily coated type for arc welding.

If heat treatment is possible it is very beneficial. With heat treatment the superiority of the iron-silicon alloy over the good quality low-carbon electrode becomes even more pronounced, as has been shown. Annealing must be thoroughly done to produce the maximum benefit. A temperature of at least 1000° C. for two or three hours in hydrogen is required. If moist hydrogen can be used and the period extended to twenty hours, the improvement in properties is truly remarkable. If the iron-silicon alloy electrode is used, and the material subsequently hydrogenized, properties approaching those of high grade silicon-iron are obtained.

The four factors tending toward best magnetic properties in welded metal then are:

1. The use of atomic hydrogen equipment.
2. Annealing at 1000° C. in hydrogen.
3. Hydrogenizing.
4. The use of a special iron-silicon electrode.

Physical Properties of Welded Cast Steel

By CHAS. H. JENNINGS

✦Paper was presented at Fall Meeting, A. W. S., Detroit, October 2nd to 6th, by Chas. H. Jennings, of the Westinghouse Research Laboratories. Contribution to Fundamental Research Committee, A. B. W.

Introduction

IN ORDER to obtain the maximum efficiency in the design and construction of welded machinery and structures, it is often desirable to incorporate into the design both rolled steel and cast steel parts[1]. Structures of this type require the welding of cast steel to cast steel, cast steel to rolled steel and rolled steel to rolled steel. A typical example of such a structure is shown in Fig. 1.

The problem of welding rolled steel to rolled steel has been extensively investigated but very little work has been done on strength of welded cast steel. As a result, the following investigation was undertaken to determine the physical properties of butt and fillet welds made on cast steel.

Preparation of Specimens

In outlining the tests for this investigation it was attempted to investigate the following points:

1. Tensile strength of fillet welds joining cast steel to cast steel.
2. Tensile strength of fillet welds joining cast steel to hot-rolled low-carbon steel.
3. Physical properties (tensile and fatigue) of butt welds made between cast steel and cast steel.
4. Physical properties (tensile and fatigue) of butt welds made between cast steel and hot-rolled low-carbon steel.
5. The effect of welding onto a cast surface. In conjunction with the above phases of this investigation duplicate tests were made in nearly every case with bare and fluxed electrodes.

The cast steel plates used in this investigation were cast at the Trafford Foundry of the Westinghouse Electric and Manufacturing Company and had the following approximate analysis and physical properties: C, 0.28%; Mn, 0.86%; Si, 0.47%; ultimate strength, 77,000 lb./sq. in.; yield point, 42,500 lb./sq. in.; elongation, 16% in 2 in.; reduction of area, 32%, and endurance limit 26,000 lb./sq. in.

[1] J. G. Ritter, "Use of Steel Castings in Welded Steel Structures," JOURNAL OF THE AMERICAN WELDING SOCIETY, 11, No. 3, p. 27.

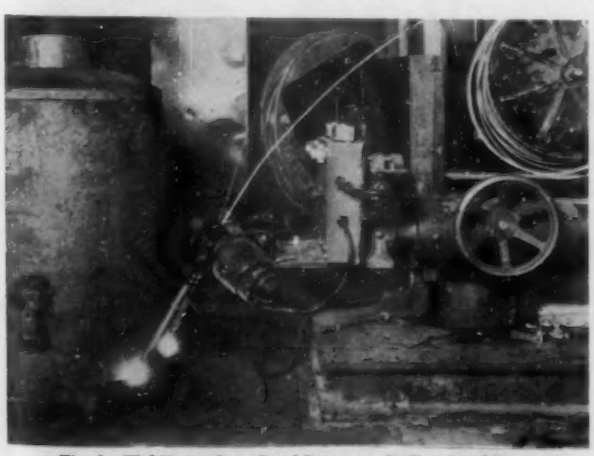


Fig. 1—Welding a Cast Steel Ring to a Rolled Steel Tank

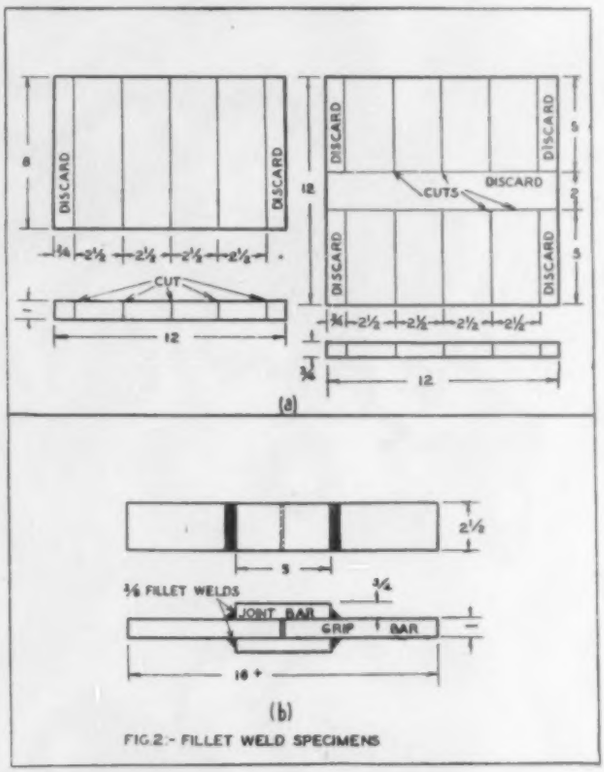


FIG. 2 - FILLET WELD SPECIMENS

Four plates 8 in. x 12 in. x 1 in. thick, 2 plates 12 in. x 12 in. x ¾ in. thick and 12 plates 12 in. x 12 in. x 1 in. thick with a 30° bevel on two sides were cast in all. The 8 in. x 12 in. x 1 in. and the 12 in. x 12 in. x ¾-in. plates were cut into coupons as shown in Fig. 2*a* and used to make fillet weld test specimens. The plates with the beveled edges were used to make the butt weld specimens. The hot-rolled low-carbon steel plates that were used in making some of the specimens had the following approximate analysis and physical properties: C, 0.12%; Mn, 0.50%; S, 0.02%; P, 0.02%; ultimate strength, 55,000 lb./sq. in.; yield point, 30,000 lb./sq. in.; elongation, 38% in 2 in.; reduction of area, 68%, and endurance limit, 27,000 lb./sq. in.

The various types of fillet weld specimens made and their corresponding numbers are given in Table 1.

On all the fillet weld specimens that contained cast steel bars the welds on one end were made so that either one or both legs were deposited on a cast surface. The welds on the opposite ends of the specimens were de-

Table 1—Fillet Weld Specimens

Specimen Number	Kind of Steel: Joint Bar (See Fig. 2*b*)	Kind of Steel: Grip Bar (See Fig. 2*b*)	Welding Electrodes
F-1, F-2	Cast steel	Cast steel	Bare electrode
F-3, F-4	" "	" "	Fluxed electrode
F-5, F-6	Hot-rolled steel	" "	Bare electrode
F-7, F-8	" " "	" "	Fluxed electrode
F-9, F-10	Cast steel	Hot-rolled steel	Bare electrode
F-11, F-12	" "	" " "	Fluxed electrode
F-13, F-14	Hot-rolled steel	" " "	Bare electrode
F-15, F-16	" " "	" " "	Fluxed electrode

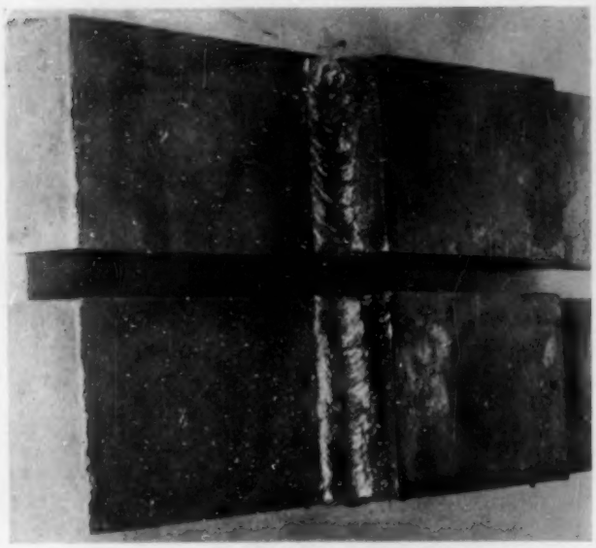


Fig. 3

posited on machined or ground surfaces. This construction made it possible to determine whether or not any difference existed between fillet welds made on cast and machined surfaces.

Typical fillet weld specimens are shown in Fig. 3.

The butt weld plates used for the static tests were welded and cut into bars as shown in Fig. 4*a*. These bars were in turn machined into tensile and bend specimens as shown in Figs. 4*b* and 4*c*, respectively. Part of the butt-welded plates used in this series of tests contained cast kerf surfaces and part contained machined kerf surfaces. (The machined kerfs were obtained by taking a $^1/_4$-in. cut off the original kerfs that had been cast onto the steel blanks.) Complete information on the butt weld specimens used in the tensile and bend tests is given in Table 2.

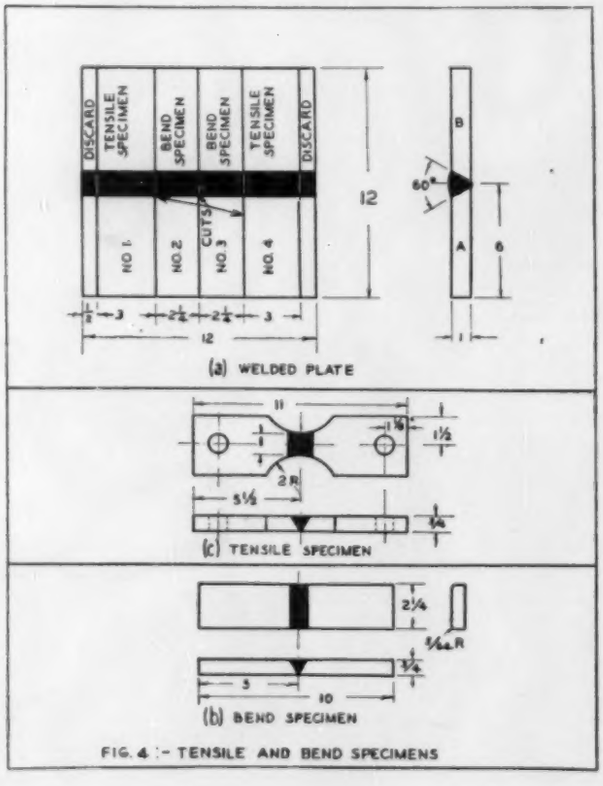


FIG. 4 — TENSILE AND BEND SPECIMENS

The welded plates used for the fatigue tests were welded and cut into bars as shown in Fig. 5*a*. These bars were in turn machined into cantilever fatigue specimens as shown in Fig. 5*b*. One of the butt-welded plates used in this series of tests contained cast kerf surfaces and the rest contained machined kerf surfaces. Complete information on the fatigue specimens is given in Table 3.

The welding electrodes used in all cases were $^3/_{16}$ in. in diameter. The welding currents employed were 180 amperes for the bare electrodes and about 190 amperes for the fluxed electrodes. The $^3/_{16}$-in. diameter electrodes were used in all of these tests because it was desired to keep the electrode size constant and they were the most suitable size for the bare electrode work and for making fillet welds in the normal position with fluxed electrodes. It would have been possible to have made the butt welds with $^1/_4$-in. or $^5/_{16}$-in. diameter electrodes, but it is felt that no difference would have been obtained in the physical properties.

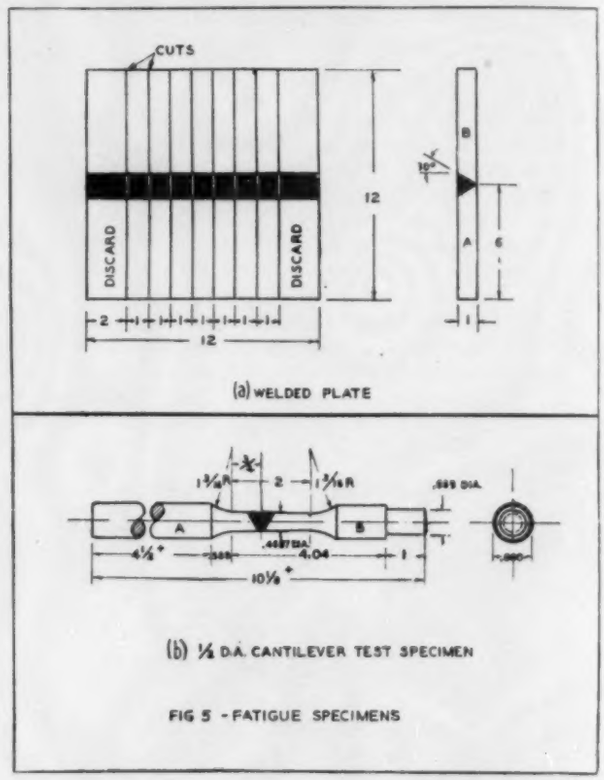


FIG 5 - FATIGUE SPECIMENS

Table 2—Butt Weld Tensile and Bend Specimens

Spec. No.	Plate A (See Fig. 4*a*)	Plate B (See Fig. 4*a*)	Welding Electrode	Condition of Kerf Surface on Cast Steel
		Tensile Specimens		
1–1, 1–4	Cast steel	Cast steel	Bare electrode	Cast
2–1, 2–4	"	"	Fluxed electrode	"
3–1, 3–4	"	"	Bare electrode	Machined
4–1, 4–4	"	"	Fluxed electrode	"
5–1, 5–4	"	Hot-rolled steel	Bare electrode	"
6–1, 6–4	"	"	Fluxed electrode	"
		Bend Specimens		
1–2, 1–3	Cast steel	Cast steel	Bare electrode	Cast
2–2, 2–3	"	"	Fluxed electrode	"
3–2, 3–3	"	"	Bare electrode	Machined
4–2, 4–3	"	"	Fluxed electrode	"
5–2, 5–3	"	Hot-rolled steel	Bare electrode	"
6–2, 6–3	"	"	Fluxed electrode	"

Table 3—Butt-Welded Fatigue Specimens

Series No. of Specimens	Kind of Steel: Plate A (See Fig. 5a)	Kind of Steel: Plate B (See Fig. 5a)	Welding Electrode	Condition of Kerf Surface on Cast Steel
A–151	Cast steel	Cast steel	Bare electrode	Cast
A–152	" "	Hot-rolled steel	" "	Machined
A–153	" "	" " "	Fluxed electrode	"
A–154	Hot-rolled steel	" " "	" "	"

The bottom portion of all the butt welds was chipped out and a layer of weld metal deposited in this chipped-out place to insure complete fusion the full depth of the plates. The fillet welds were made with the specimen in the horizontal position. Two layers were used to make the $^3/_8$-in. fillets with the fluxed electrodes and one layer with the bare electrodes.

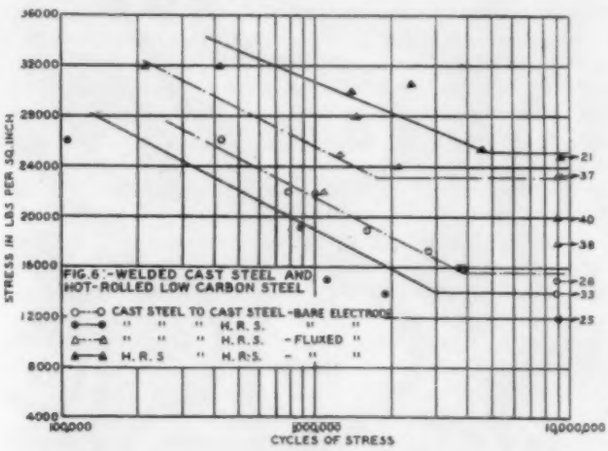


Fig. 6

Test Procedure and Results

The fillet weld specimens were tested in tension in a 400,000-lb. Olsen testing machine and the butt-welded tensile and bend specimens were tested in a 100,000-lb. Amsler testing machine. The fatigue tests were made in the ordinary way by testing a complete series of specimens to determine the endurance limit.

The data obtained from the various tests are tabulated in Tables 4 to 7, respectively.

Endurance curves plotted from the fatigue data are shown in Fig. 6.

Discussion of Test Results

The results of the fillet weld tests show that satisfactory welds of this type can be made on cast steel. The ultimate strength of the bare electrode welds averaged about 64,000 lb./sq. in. for all combinations of plates. The ultimate strength of the fluxed electrode welds averaged from 72,000 to 80,000 lb./sq. in. depending upon the combination of plates welded.

The fractures of all the bare electrode welded specimens occurred through the throat of the welds. This accounts for the results of the specimens being practically the same. The fractures of fluxed electrode specimens occurred in either of two places, through the weld throat or along the shear plane of the weld on the grip bar[2] (see Fig. 7). The shear plane type of failure occurred only when the grip bars were made of hot-rolled

[2] The weld stresses were computed on the basis of the weld throat irrespective of the type of failure.

Table 4—Data on Fillet Weld Tests

Specimen No.	Electrode	Location of Failure	Failure with Respect to Cast or Machined Surfaces	Ultimate Strength
		Cast Steel Welded to Cast Steel		
F–1	Bare	Weld throat	Cast	66,500
F–2	"	" "	Machined	66,500
				Av. 66,500
F–3	Fluxed	" "	"	79,800
F–4	"	" "	Cast	81,000
				Av. 80,400
		Hot-Rolled Steel Welded to Cast Steel		
F–5	Bare	Weld throat	Cast	63,700
F–6	"	" "	Machined	64,600
				Av. 64,200
F–7	Fluxed	" "	"	79,100
F–8	"	" "	"	77,300
				Av. 78,200
		Cast Steel Welded to Hot-Rolled Steel		
F–9	Bare	Weld throat	Cast	63,500
F–10	"	" "	Machined	63,100
				Av. 63,300
F–11	Fluxed	Shear plane	Cast	69,100
F–12	"	" "	"	76,000
				Av. 72,600
		Hot-Rolled Steel Welded to Hot-Rolled Steel		
F–13	Bare	Weld throat	.....	61,000
F–14	"	" "	.....	65,900
				Av. 63,400
F–15	Fluxed	Shear plane	.....	74,600
F–16	"	" "	.....	69,100
				Av. 71,800

Table 5—Tensile Data on Butt Welds

Spec. No.	Kind of Steel	Welding Electrode	Kerf Surface	Ultimate Strength	Remarks
1–1	Cast steel to cast steel	Bare	Cast	65,600	Broke in weld
1–4	" " " " "	"	"	71,800	" " "
				Av. 68,700	
2–1	Cast steel to cast steel	Fluxed	Cast	73,300	Failed in fusion zone
2–4	" " " " "	"	"	76,200	" " " "
				Av. 74,700	
3–1	Cast steel to cast steel	Bare	Machined	59,700	Failed at fusion zone
3–4	" " " " "	"	"	62,900	" " " "
				Av. 61,300	
4–1	Cast steel to cast steel	Fluxed	Machined	79,000	Broke in weld
4–4	" " " " "	"	"	76,000	" " "
				Av. 77,500	
5–1	Cast steel to hot-rolled steel	Bare	Machined	64,300	Failed in weld
5–4	" " " " " "	"	"	59,000	Spot of poor fusion to cast steel
				Av. 61,600	
6–1	Cast steel to hot-rolled steel	Fluxed	Machined	69,100	Failed in hot-rolled steel at fusion zone
6–4	" " " " " "	"	"	68,200	" " " " " " " "
				Av. 68,700	

Table 6—Bend Test Data on Butt Welds

Specimen No.	Kind of Steel	Welding Electrode	Kerf Surface	Elongation, %	Remarks
1–2	Cast steel to cast steel	Bare	Cast	8.0	
1–3	" " " " "	"	"	8.0	
				8.0	
2–2	Cast steel to cast steel	Fluxed	Cast	26.7	
2–3	" " " " "	"	"	16.0	Failure at fusion; small spot of poor fusion
3–2	Cast steel to cast steel	Bare	Machined	10.7	
3–3	" " " " "	"	"	8.0	
4–2	Cast steel to cast steel	Fluxed	Machined	33.3	
4–3	" " " " "	"	"	33.3	

NOTE: It was impossible to test the specimens of cast steel welded to hot-rolled low-carbon steel because of the large difference in the strength of the two materials. Under test the bend occurred entirely in the hot-rolled steel and not in the cast steel or the weld.

Table 7—Fatigue Data on Butt Welds

Specimen No.	Stress, Lb./ Sq. In.	Cycles of Stress	Remarks
	Cast Steel to Cast Steel—Bare Electrodes		
A–151–1	22,000	783,000	Failure in weld
2	19,000	1,610,000	" started at hole in fusion zone
3	16,000	3,860,000	Failure in weld
4	14,000	33,000,000	No failure
5	26,000	430,000	Failure in weld
6	17,500	2,830,000	" " "
7	15,000	28,000,000	" " "
	Endurance Limit, 15,800		
	Cast Steel and Hot-Rolled Low-Carbon Steel—Bare Electrodes		
A–152–1	22,000	1,000,000	Failure in weld
2	19,000	870,000	" " "
3	15,000	1,100,000	" " " cast steel end
4	12,000	25,000,000	No failure
5	16,000	3,700,000	Failure in center of weld
6	14,000	1,850,000	Failure started at hole in fusion zone of cast steel
7	26,000	105,000	Failure started at hole in fusion zone of cast steel
	Endurance Limit, 14,000		
	Cast Steel to Hot-Rolled Low-Carbon Steel—Fluxed Electrodes		
A–153–1	25,000	1,260,000	Failure center of weld
2	22,000	1,070,000	Failure in weld at cast steel end
3	18,000	38,000,000	No failure
4	20,000	40,000,000	" "
5	23,500	37,000,000	" "
6	32,000	210,000	Failure at fusion zone cast steel end
7	24,000	2,100,000	Failure at fusion zone cast steel end
	Endurance Limit, 23,200		
	Hot-Rolled Low-Carbon Steel to Hot-Rolled Low-Carbon Steel—Fluxed Electrodes		
A–154–1	28,000	1,450,000	Failure in weld and base metal
2	25,000	21,000,000	No failure
3	32,000	415,000	Failure in weld
4	26,500	2,460,000	" " "
5	26,000	1,400,000	Failure started at fusion zone
6	25,500	4,500,000	" " " " "
7	36,000	75,000	Failure in base metal
	Endurance Limit, 25,200 lb./sq. in.		

low-carbon steel. The explanation of these two types of failure and their effect upon the strength of the joint is as follows: Under normal conditions, where the tensile strength of the weld is only slightly higher than that of the base metal, failure occurs at the throat of the weld which is the smallest in cross section and the highest stressed. If, however, the tensile strength of the weld metal greatly exceeds that of the base metal, failure will occur along the shear plane of the grip bar (see Fig. 7).

For fractures of the shear plane type it is evident that the ultimate strength of the joint is dependent upon the strength of the parent metal. Consequently, for a given parent metal no matter how strong the weld metal is, no increase in joint strength can be obtained above the value that causes failure to occur at the shear plane. This is the condition that is present with the fluxed electrodes and accounts for the variation in test results. The F–11, F–12, F–15 and F–16 specimens contained grip bars of hot-rolled low-carbon steel (ultimate strength = 55,000 lb./sq. in.) and failure occurred along the shear plane giving calculated ultimate strengths of about 72,000 lb./sq. in. The Numbers F–3, F–4, F–7 and F–8 specimens contained grip bars of cast steel (ultimate strength = 77,000 lb./sq. in.) and failure occurred at the weld throats giving ultimate strengths of about 80,000 lb./sq. in. Had the ultimate strength of the hot-rolled steel been equal to that of the cast steel, failures would have occurred through the weld throats and the ultimate strengths would have been equal to those obtained from the F–3, F–4, F–7 and F–8 specimens.

Inspection of Table 4 indicates that failure occurred at welds made on both the cast and machined surfaces with no preference to either. The only noticeable difference between the welds made on the different surfaces was that those made on the cast surfaces had

Fig. 7—Showing Types of Fillet Weld Failure

Fig. 8—Typical Tensile and Bend Specimens of Welded Cast Steel

a tendency to be slightly more porous. This condition was not bad, however, and it is felt that it could be eliminated by proper welding procedure.

The results of the butt-weld tests are a little erratic, but in no case did any of the specimens fail at less than 59,000 lb./sq. in., and this was a weld made with a bare electrode. The fluxed coated electrodes all developed ultimate strength above 68,000 lb./sq. in. Some were as high as 79,000 lb./sq. in.

It will be noted that all but two fractures occurred either in the weld or at the fusion zone. This is the result of the particular tensile specimen used which is designed to produce failure in the weld metal proper[3] (see Fig. 4*b*).

The fluxed electrode welds made on machined kerf surfaces appeared to be slightly stronger than those made on cast surfaces, while the bare electrode welds appear to produce the reverse effect. The bare electrode welds made on the machined kerf surfaces failed in the fusion zone with indications of small spots of poor fusion and this undoubtedly is the explanation for the lower results in this case.

The fluxed electrode welds between cast steel and hot-rolled low-carbon steel developed the lowest ultimate strength of any of the fluxed electrode welds (68,700 lb./sq. in. as compared to 74,700 and 77,500 lb./sq. in.). This is the result of failure occurring in the low-carbon steel rather than the welds proper.

Summing up the results of all the butt-weld tensile tests, it appears that little or no difference in strength is obtained between welds made on cast or machined surfaces and that strong welds can be made with both bare and fluxed electrodes between cast steel and cast steel and cast steel and hot-rolled low-carbon steel.

As a matter of comparison, it is important to point out that welds made on hot-rolled low-carbon steel with bare and fluxed electrodes will develop ultimate strengths of over 60,000 and 70,000 lb./sq. in., respectively.[3]

The results of the bend tests are given in Table 4. These results show values comparable with those obtained on welds made on hot-rolled low-carbon steel (bare electrodes, 8 to 12%, coated electrodes, 30 to 40%). In this case there appears to be a slight difference between the ductility of welds made on cast and machined surfaces, the better results being obtained from the machined surfaces. This difference is slight, however, and is not of great importance.

Typical tensile and bend specimens of butt welds are shown in Fig. 8

In considering the fatigue data it will be noted that the endurance limits obtained for a given type of electrode, irrespective of the combination of plates welded, were practically the same. (The small variations that were obtained are well within the allowable experimental error.) This is the condition that would be expected when one considers the results of the tensile tests and that all failures occurred either in the welds or the fusion zone.

No fatigue tests were made on cast steel welded to cast steel with fluxed electrodes, but it is reasonable to assume on the basis of the other tests that the endurance limit would be practically the same as that obtained from the series of specimens of cast steel welded to low-carbon steel.

As a matter of comparison, the endurance limits obtained in this series of tests are tabulated in Table 8 along with the endurance limits of parent metal and welds made on low-carbon steel with bare electrodes.

[3] Chas. H. Jennings, "Ductility in Arc Welds with Some Reference to Strength Values," JOURNAL OF THE AMERICAN WELDING SOCIETY, 11, No. 4, April 1932, p. 37.

Table 8—Endurance Limits of Welded Joints
(As obtained from 1/2-in. diameter cantilever fatigue specimen.)

Materials Welded	Welding Electrodes	Endurance Limit, Lb./Sq. In.
Cast steel to cast steel	Bare	15,800
Cast steel to hot-rolled steel	Bare	14,000
Hot-rolled* steel to hot-rolled steel	Bare	16,000
Cast steel to hot-rolled steel	Fluxed	23,200
Hot-rolled steel to hot-rolled steel	Fluxed	25,200
Cast steel (parent metal)		26,000
Hot-rolled low-carbon steel (parent metal)		27,000

* This value is taken from a previous test not included in this particular investigation.

Examination of this table shows that the endurance limits of the three series of bare electrode welds are practically the same and that they are from 40 to 50% lower than the endurance limits of the parent metals. The endurance limits of the fluxed electrode welds are also approximately the same but in this case they are practically equal to those of the parent metals. The important points, however, are: the much superior results obtained by the fluxed electrodes and the fact that the endurance limits of welded cast steel joints are practically the same as those of welded hot-rolled low-carbon steel joints.

Conclusion

The results of this investigation bring out the following important points:

1. Cast steel (of the composition used in this investigation) can be successfully arc welded to cast steel or hot-rolled low-carbon steel by means of bare and fluxed electrodes.

2. Welding on cast surfaces is not harmful and the results obtained are approximately equal to those obtained from welds made on machined surfaces.

3. The average tensile properties obtained from welds made on various combinations of cast and hot-rolled low-carbon steel are as follows:

Type of Joint	Bare Electrodes	Fluxed Electrodes
Fillet welds	64,300 lb./sq. in.	75,000 lb./sq. in.
Butt welds	63,000 lb./sq. in.	73,600 lb./sq. in.

4. The ductility obtained from welds made on various combinations of cast steel to cast steel as obtained by the free-bend method is, bare electrodes, 8.0%, fluxed electrodes, 27.0 to 33%.

5. The fatigue strengths obtained from welds made on various combinations of cast and low-carbon steel are as follows:

Combination of Welded Plates	Bare Electrodes	Fluxed Electrode
Cast steel to cast steel	15,800 lb./sq. in.	.....
Cast steel to hot-rolled steel	14,000 lb./sq. in.	23,200 lb./sq. in.
Hot-rolled steel to hot-rolled steel	16,000 lb./sq. in.	25,000 lb./sq. in.
Cast steel (parent metal)	26,000 lb./sq. in.	
Hot-rolled low-carbon steel (parent metal)	27,000 lb./sq. in.	

Acknowledgment

The writer wishes to acknowledge the assistance rendered by Mr. Frank Cassel in making the fatigue tests reported in this investigation. Special acknowledgment is also given to Mr. R. E. Peterson, Manager of the Mechanics Division of the Westinghouse Research Laboratories, for his interest in this work.

Modern Rail Welding without Interrupting Traffic

By J. H. DEPPELER

✦Paper presented at Fall Meeting, A. W. S., Detroit, Oct. 2nd to 6th, by J. H. Deppeler, Chief Engineer and Works Manager, Metal & Thermit Corp.

FROM time to time I have reported to you the progress made in Thermit welding and as years ago this reached a state where improvements although important were, nevertheless, not spectacular to the outsider, the reports have been naturally few and far between.

The welding of street railway rails was naturally affected by the depression which eliminated most of the new construction work. Some properties continued their extension programs but they were exceptions. Fortunately, however, much of this loss of new construction welding was replaced by maintenance and repair welding, the importance of which has steadily grown. Unlike new construction work, this maintenance welding almost invariably had to be done without interrupting traffic. Traffic naturally tends to restrict production slightly, but experience has shown that it has much less effect on the number of welds installed per day or per man-hour than was at first supposed. This experience was gained in a very natural way on those properties where maintenance welding first became important. These properties, having adopted for maintenance work the types of welds and designs of molds which would allow car wheels to pass over the joint during the making, naturally preferred to standardize on one type of equipment and, therefore, used the same designs and molds for their welding work where traffic had been removed and also in other cases where traffic was continued during the construction; but the type of construction did not consist of the cutting in of short lengths of rails.

The one feature of maintenance work which for years

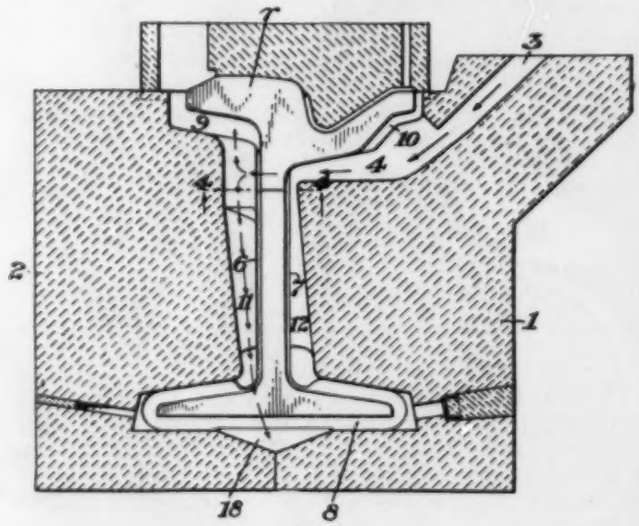
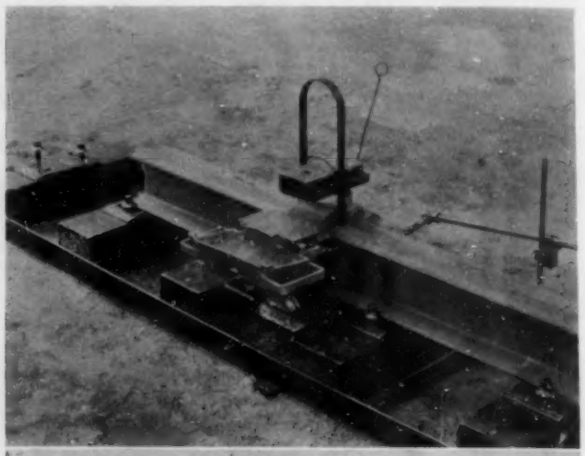


Fig. 1

Fig. 2



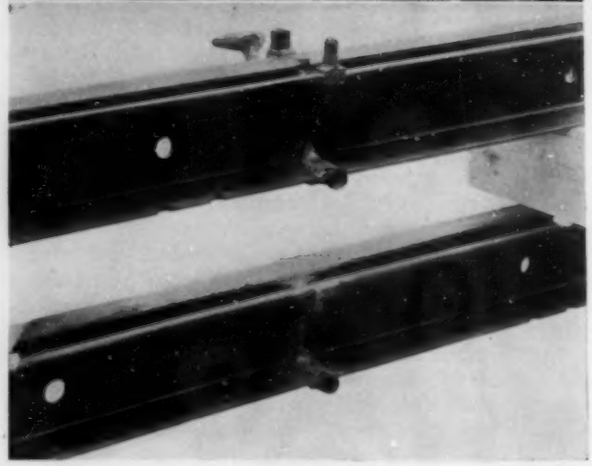
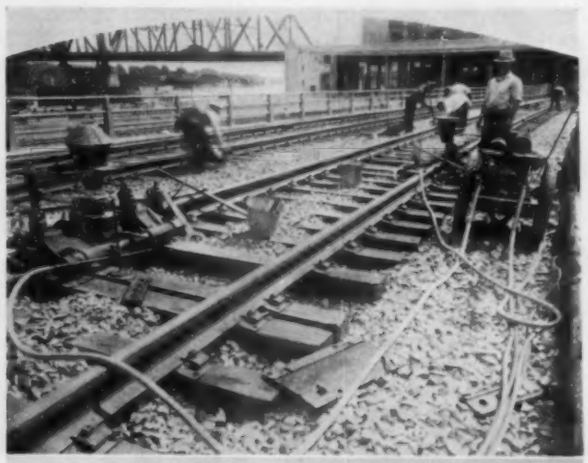


Fig. 3

delayed the universal use of Thermit welding was the fact that this maintenance was not on track that had been previously Thermit welded but usually on the ordinary plated and bolted joint, and maintenance was delayed until the joint had pounded badly, necessitating the cutting in of a short length of rail to replace the defective joint. This meant the installation of two Thermit welds to replace one defective joint, practically doubling the number of Thermit welds per mile of track, and naturally greatly increasing the expense.

Now we are talking of embedded track, of course, and the problem of installing a short length of rail is even greater than simply the making of two Thermit welds because of the rigidity of the rail on either side of the cut-in. These problems consist of the mechanical difficulties of supporting the short length sufficiently to withstand traffic and to hold the strut rigid during the welding of the short length at its two ends. The solution of this problem was found in the use of strong clamps designed not to interfere with traffic but to draw the rail ends tightly together at the joints so as to avoid relative motion. This is easy naturally at the first end of the loose piece but is more difficult at the second end. Production is, furthermore, greatly retarded by the necessity of allowing the first weld on a cut-in to cool down before the other end is welded, as without this precaution the cooling of the welds would introduce sufficient strain to break the short end of the rail at its weakest point. Even though the first weld is allowed to become cold, still additional precautions must be taken not to introduce too great a tension in this short length by the welding of the second joint and to avoid this strain the cut-in

Fig. 4



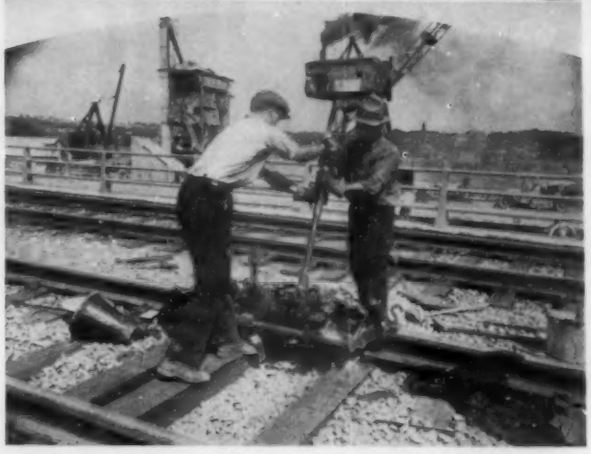


Fig. 5

piece is put under compression by means of slow tapered steel wedges driven in between the rail ends. When this closing joint is opened as far as possible by this wedging operation, an insert of rail steel is fitted in between the rail heads and the wedge withdrawn. Even with all this, this second joint must not be preheated too highly, because in doing so the insert may become softened sufficiently to allow the high compression to upset it and tension will again be introduced.

Obviously, the lesson from all this is that much future trouble can be saved by the Thermit welding of the rail as it is laid, thus avoiding all future maintenance, but regardless of this the most permanent cure for defective bolted joints is to Thermit weld them even though this may require the welding in of short pieces of rail.

The type of joint used in this maintenance work may be either the well-known Center Pour Weld, which has been standard with most street railway companies for many years, or the more recently introduced Cross Center Pour Weld, which was described to you in a paper about a year ago and which in cross section is about as shown in Fig. 1.

Figure No. 2 shows the complete set-up of the Cross Center Pour Weld during the preheating operation. The contrivance on top of the rail consists of a cast-iron heating cover resting on the rail itself and designed to deflect the hot gases and circulate them around the heavy upper portions of the rail head. Directly above this heating cover and secured to the same curved handle is a shelf on which is placed the flat rectangular cope. This cope is of light iron construction with its own smaller curved handle, and inside of the iron frame is composed of molding material previously formed to suit the contour of the head of the rail. It is positioned during the preheating operation directly above the iron heating cover and is thoroughly dried out by the radiated heat from below. Whenever cars pass, all of these parts are lifted off as a unit without interrupting the preheating and are replaced immediately afterward. The $^1/_4$-in. rod sticking out diagonally from the back of the heating cover is a loose piece whose lower end is placed into a lug designed to support it and during the preheating operation is brought to a red heat so as to be used in igniting the ignition powder, which will in turn ignite the Thermit charge in the crucible. The flat, rectangular basin on the near side of the mold box is removable and designed to catch the alumina slag which will come from the crucible after the Thermit reaction and overflow the mold.

Figure 3 at the top shows the Cross Center Pour Weld before the pouring gate and risers are removed and at the bottom the finished rail joint. Cars may be allowed to pass almost immediately after the weld is poured although it is better, if possible, to allow a minute or two for the weld metal to solidify.

The welding of new construction work with this type of equipment is usually done by a gang of nine or ten men; and with the work properly coordinated and the aligning and surfacing of the rails done in advance, a production of thirty-five to forty joints a day is not unusual. Where maintenance work is being done, the work cannot be so easily organized and is usually handled by a smaller number of men in each unit and working practically independently.

Fig. 6

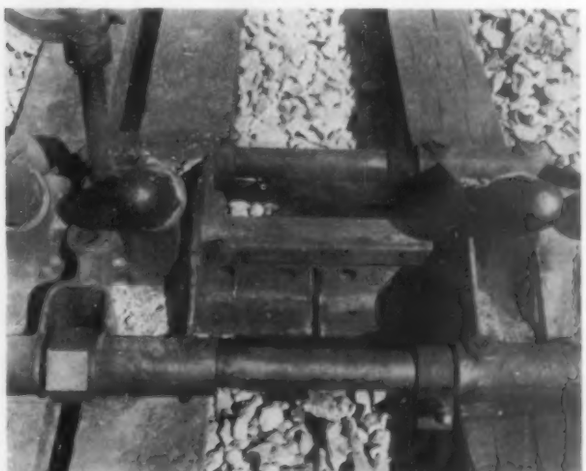


Fig. 7

Although the subject of this paper indicates that it will be confined to welding without interrupting traffic, some of the newer developments in the welding of open track on steam railroad lines are so important that I am taking the liberty of bringing this to your attention at this time. The type of joint used in the welding of open track on steam railroads is, as most of you know, a combined pressure and fusion weld in which the base and web of the rail are fusion welded and the heads pressure welded. The heat for the pressure weld is furnished by the alumina generated in the Thermit reaction which, after the steel fills the mold to approximately the under side of the head, flows around the heads of the rails and in a few minutes brings them to a temperature at which they can be pressure welded. The application of this pressure requires heavy clamps which in their present design at least make it impossible to consider the making of these welds under traffic. This type of weld is considered important in steam railroad work because of the flexibility of the road bed and the enormous weight of locomotives and other equipment. The high wheel loads and resilient support introduce bending moments which require an absolutely perfect weld on the upper extreme fibers of the rail head, which is not so important in street railway work. Figure 4 shows such an installation on the main-line track of a well-known eastern road. The very heavy clamp at the left is of an earlier design; the later design shown on the opposite rail weighs only about half as much. The cut shows the typical staggered joint construction with a weld being made on each rail at the same time; the machine on wheels at the right is the kerosene and air preheater. Particular attention is called to the tie plates and rail fastenings. This tie plate provides a shoulder on each side of the rail base which is considered of utmost importance when open track is welded into long lengths.

Fig. 8

Fig. 9

In Fig. 5 the operation of machining the ends of the rail heads is shown. This is accomplished by a self-feeding, hand-operated tool, the bit being like that of a shaper. As it passes across the end of the rail head, the tool reverses and by this means cuts in both directions. The shaping of the rail heads, although done by hand, because on the steam railroad power is not available, nevertheless takes only four to five minutes even though more than one cut need be taken to make the ends parallel and true. When this is completed, the shaping machine is removed and the rail clamps operated to force the rail heads together. Figure 6 shows a close-up of the rail ends ready for welding with the machined heads tight together and a space provided by means of a cutting torch between the webs and bases of the rails preparatory to fusion welding.

In Figs. 7 and 8 are shown various methods of finishing the welded rails; usually this is done by draw-filing, as shown in Fig. 8, because of the difficulty of obtaining a supply of electric power. The draw-filing is, of course, expensive in labor but the quality of the finished weld cannot be surpassed. In Fig. 7 is shown a gasoline-driven electric generator, which for convenience was crudely mounted on a flanged wheel truck and which supplied the power for the operation of the rotating wheel grinder used in the preliminary roughing operation and the reciprocating type used for the finishing operations. Figure 9 is a close-up of the finished weld.

This type of pressure weld has been given a number of heavy service tests over a period of two to three years—some of these on main-line track and others in freight classification yards—and even after this length of time the joints cannot be located by an examination of the top of the rail, but only by the excess metal of the fusion weld in the web and base. Moreover, the installation pictured here is fully expected to confirm the findings on the State Railways of Germany that temperature change will cause tension and compression in the steel of a rail itself but will otherwise cause no motion and that even where the rail is made continuous for a thousand feet or more, expansion joints are not necessary at the ends but ordinary bolted joints will do. In this particular installation it was at first planned to leave an open joint at the end of each five welded rail lengths and in this way about 2691 ft. of both the northbound and the southbound track were welded, and when one of these was completed an extremely hot day was encountered in which the rail temperature reached 156° F. It was naturally thought that this high temperature would close all of the unwelded joints tightly but when they were examined and found to be $^1/_4$ in. open, which was the amount left at the time of welding, it was decided that it would be perfectly safe to weld these expansion joints and make the entire 2691 ft. continuous rail without joints.

Besides the elimination of battered and pounded rail ends, the welding overcomes a very serious trouble, and that is creepage. The shorter rail lengths gradually move in the direction of traffic regardless of carefully designed anti-creepers, and if the rail were not constantly maintained in alignment and surface the gage would spread at curves and derailments would result. A number of rail lengths welded together will not so creep, and where a thousand feet or more of rail are made continuous creepage is not present and anti-creepers may be dispensed with.

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